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SLATE
IN
PENNSYLVANIA

By

Charles H. Behre, Jr.

DEPARTMENT OF INTERNAL AFFAIRS
PHILIP H. DEWEY, Secretary

TOPOGRAPHIC AND GEOLOGIC SURVEY
GEO. H. ASHLEY, State Geologist
HARRISBURG, PA.

1933

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Commonwealth of Pennsylvania
Department of Internal Affairs

Harrisburg, Pa., February 2, 1932

Honorable Philip H. Dewey
Secretary, Internal Affairs
Harrisburg, Pennsylvania

My dear sir:

I have the honor to transmit herewith the manuscript, maps, and illustrations of a very detailed report on Slate in Pennsylvania, by Charles H. Behre, Jr. This report includes also the material of a previous report, Bulletin M-9, Slate in Northampton County, by the same author, which was burned before it had been widely distributed.

The slate industry, in which Pennsylvania leads the United States, is one of the largest of our smaller mineral industries. In recent years it has been hard hit by the introduction of artificial substitutes for roofing and other uses. In view, however, of the unquestionable superiority of natural slate for certain purposes, the quarrying of slate is bound to continue as a considerable industry. The discovery of new uses for slate may even increase the output.

This report is a minute study of those factors that determine the workability and value of the slate. No such careful study has ever before been made, and it should therefore be of large value to the men in the industry. The illustrations will be a revelation to many of our citizens as to the size and scope of the industry, the size and depth of the quarries, the processes of quarrying and preparing the slate, and the great volume of waste slate for which a use is being sought. Geological understanding is of prime importance in solving many of the problems of the industry.

The field work for this report was begun by Prof. Behre in 1923 when he was a member of the geologic faculty of Lehigh University. It was continued while he was a member of the faculty of the University of Cincinnati, and the report was completed at Northwestern University where he is associate professor of Economic Geology. All of the work has been done under the auspices of the Pennsylvania Topographic and Geologic Survey. This Survey is deeply indebted to the three universities for fostering the work by allowing the use of research time, library and laboratory facilities for the preparation of the report.

Respectfully submitted,

Geo. H. Ashley

L304053

State Geologist.

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SLATE IN PENNSYLVANIA

By CHARLES H. BEHRE, JR.

INTRODUCTION

PURPOSE OF THE REPORT

As the United States becomes more and more industrialized the non-metallic mineral products play an increasingly significant role in manufacturing industries. Of these non-metallics, slate, though not of leading importance, is nevertheless one of the more valuable. In recent years it has been twenty-second in order of worth among the mineral products of this country, its annual production value amounting to approximately \$12,000,000. Pennsylvania is the leading slate-producing State in the Union. Here slate is ninth in value among the minerals mined and in recent years approximately \$5,000,000 worth, or about 45 per cent of the national total, has been quarried and milled annually.

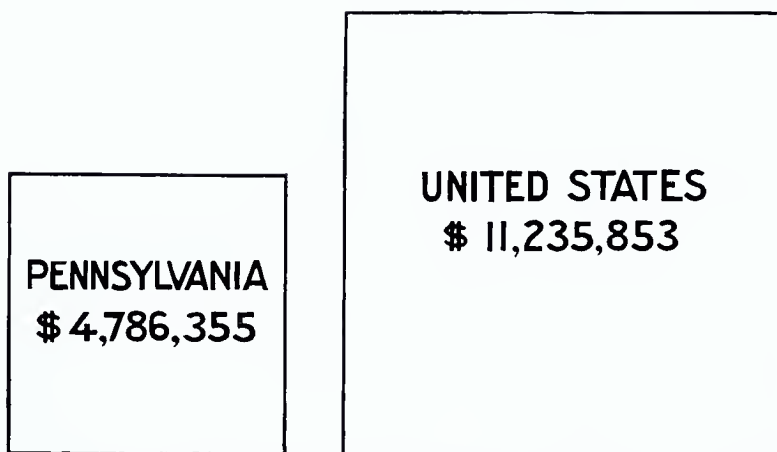


Fig. 1. Value of slate production in 1929 in the United States and Pennsylvania, compared.

It is clear that this important mineral product is a noteworthy source of wealth to the State and to the nation. At once there arise several questions. Are all of the slate deposits that may be of commercial value known? Are the known deposits worked to the best advantage? These two queries, both of an eminently practical nature, justify a careful study of the slate deposits of Pennsylvania.

Practical as are the problems of discovery and utilization, however, they cannot well be solved without a fundamental understanding of the physical and chemical properties of slate, its peculiar structure and origin, and the geological conditions favorable or unfavorable to its formation. The general purposes of this report, therefore, are first, to help lay the theoretical groundwork by a consideration of the constitution and origin of slate in general; and second, to present what geology has to say regarding the application of these more theoretical principles to the problems of slate quarrying.

At the same time certain specific questions may also be faced. In so far as time and appropriations permitted, the general geology of each slate district in Pennsylvania has been studied, and maps and cross-sections have been prepared to show the distribution and structure of workable slate beds. The physical qualities and the chemical and mineralogical constitution of the slates of each district are discussed. Every accessible slate quarry or mine has been visited and briefly described, with as much of its past history as seems pertinent in guiding development. A summary of production methods is introduced, as of value to quarry and mill manager, but a more detailed discussion of this subject is thought to be more properly the field of the mining, quarry, and mechanical engineer. Finally, production figures for the various districts of the State are given.

This publication includes many data already presented in an earlier bulletin.¹ The reader thus has before him a book dealing with all of the slate deposits of Pennsylvania.

The reader may regard as tiresome the detailed description of each quarry,—an approach not generally used in discussing non-metallic minerals, though sanctioned by custom in other geologic writings. The more exhaustive plan has been followed here for two reasons. First, the quarry operator is not always able to apply the printed generalized statements about regional geology to his own particular problems. Second, and far more important, however, is the fact that the slate deposits are sufficiently well known so that a discussion of general geology is not really a new contribution for the operator: rather, his quarry is a problem in itself, with its peculiar system of joints, its individually differing beds, and the like, and these facts must be faced concretely by the economic geologist if he is to be of real service to the industry. The writer hopes that his highly detailed approach will be recognized as valid and that the precedent set by metal mine reports may perhaps come to be more generally followed in the technical description of non-metallic mines and quarries.

FIELD AND OFFICE WORK

The earlier field work in preparing this publication was carried on under the auspices of the Pennsylvania Topographic and Geologic Survey during the summers of 1923 and 1924. Based upon this work and shorter field trips during the winters of the years mentioned, a detailed report, on the slate deposits in Northampton County east of Danielsville, was prepared and published in 1927, as Bulletin M-9 of the Survey.¹

In May, 1927, a fire destroyed the reserve stock of this earlier report. The accident, but especially the fact that the bulletin covered only a part of the Pennsylvania slate deposits, made the preparation of a new report desirable, and the writer was commissioned to begin field work in 1927. The summer season was devoted to a study of all of the slate deposits not described in Bulletin M-9. From time to time subsequently trips were made into the slate regions for the purpose of rounding out the data. Office work was distributed irregularly through the calendar years of 1928-1930.

¹ Behre, C. H., Jr., *Slate in Northampton County, Pennsylvania*: Penn. Topog. and Geol. Survey Bull. M-9, 308 pp., 1927.

The field and office methods were like those used in other, similar geologic studies. The topographic sheets prepared by the U. S. Geological Survey served as base maps; it should be stated, however, that quarries are largely omitted from these, and hence the writer, assisted by others, plotted quarry locations by plane table methods.

SOURCES OF INFORMATION

Two general sources of information other than that obtained by personal observation, were available in preparing this bulletin,—the reports of earlier geologists and the statements of quarrymen. Many great names among the pioneers of geology appear in all fundamental works on slate. Among these are Daubree, Jannetaz, Sorby, Renard, Van Hise, Becker, and Leith. In particular, the excellent work of Dr. T. Nelson Dale of the United States Geological Survey became the foundation upon which these studies could be built. The general stratigraphy and structure of this and adjacent regions have been described in more or less detail by the geologists of the United States, Pennsylvania, New Jersey, and Maryland Geological Surveys. Dr. Oliver Bowles of the United States Bureau of Mines has given in his writings much valuable information on the technology of slate. Production data were obtained from the Mineral Resources Division of the United States Bureau of Mines.

For information as to the development of individual slate quarries some of the pioneers in the slate district were consulted. Many abandoned quarries are now inaccessible, so that details of structure and stratigraphy could not be studied and data could be gleaned only from the men who were once engaged in quarrying in these particular openings. In the use of such data the writer has sought to discriminate between statements that appear to be in accord with observed facts and those which, because of the filling of the openings or similar causes, could not be tested and have to be accepted, if at all, "on faith."

ACKNOWLEDGMENTS

To express appreciation of all the assistance received in preparing this report would be to fill several pages. Especial thanks are due Prof. B. L. Miller of Lehigh University for initiating these studies and for helpful counsel throughout the work; to Mr. R. W. Stone, Assistant State Geologist of Pennsylvania, for his careful editing of this publication; to Mr. Homer H. Kirby, of the Interstate Commerce Commission, for his contribution on the valuation of slate lands, republished with slight alterations from the earlier Bulletin M-9; to Messrs. Malcolm K. Buckley, Chester Lancaster, and Robert Notvest, for chemical analyses of slate; to Dr. George P. Merrill of the U. S. National Museum, lately deceased, for the loan of some fifty thin sections of American slates; and for kindly and helpful criticism and suggestions to Professors Edson S. Bastin and R. T. Chamberlin of the University of Chicago, to Professors Nevin M. Fenneman, Walter H. Bucher, and Otto C. Von Schlichten, of the University of Cincinnati, to G. F. Loughlin, E. O. Ulrich, Geo. W. Stose, and Anna I. Jonas of the United States Geological Survey, and to Oliver Bowles of the U. S. Bureau of Mines.

The heartiest cooperation and most kindly assistance was given by the slate operators. To acknowledge full indebtedness would be im-

possible, but special mention should be made of the aid furnished by certain individuals. These include in the Lehigh-Northampton district W. L. Blake, Wm. H. Smith, and M. J. Spry of Bangor, and Wm. Bray of East Bangor, recently deceased; the officials of the Structural Slate Company of Pen Argyl, especially N. M. Male and Wm. A. Kitto; Richard Jackson, 3d, of Pen Argyl; Wm. Smith of Chapman, Pa.; Henry Seip and J. K. Hower of Danielsville; Wm. Kuhnsman, Reuben Steckel, Edw. Williams, and Peter Snyder of Slatington; Wm. Foulk of Slatedale; and the officials of the Vendor Slate Company, especially Doster Focht. In the Peach Bottom district W. J. Thomas and E. E. Williams of West Bangor, John W. Jones, H. P. Reese, and Richard Reese of Delta, Pa., and Thurman Shank, Charles Owens, and Arthur Roberts of Peach Bottom were especially helpful. Efficient assistance as rodmen was rendered by John Snyder, Elwood Prestwood, and Robert Prestwood, all of Slatington.

The Bliss Studio of Easton, Pa., furnished several photographs.

My wife, Dr. J. A. Behre, was a constant help in field and office, especially in her skillful use of the alidade and plane table during the earlier field seasons, and in offering constructive criticism and suggestions.

SLATE RESOURCES OF PENNSYLVANIA

The slate reserves of Pennsylvania extend areally through large parts of the southeastern quarter of the State, and in point of time through parts of the pre-Cambrian and the later Cambrian, Ordovician, and Devonian periods of the Paleozoic Era. In character the available slate ranges from a dense, highly metamorphosed rock with undulating cleavage, with little or no traces of the original bedding, closely akin to schist in mineral composition and in structure, to a relatively poorly consolidated, irregularly flaking clay slate, having a marked kaolin odor and a tendency to part parallel to the bedding.

Differences in age, structure and composition are in general related to differences in geographic distribution. Only in relatively isolated areas and in separated periods of the earth's history have the rocks had the peculiar combination of that original composition and that degree of alteration by pressure needed to produce commercial slate. Since in a region of folded rocks, such as the State of Pennsylvania, strata of a certain age are generally exposed at the surface over relatively small areas only, there is a further limiting geographic factor in the surface occurrence and accessibility of individual beds or groups of beds of workable slate. For these reasons any given region generally includes slate beds which are roughly uniform as to composition, structure, and geologic age. This makes it possible to classify the slate belts of Pennsylvania into several districts.

A slate district may be defined as a geographic unit in which the workable beds have a virtually continuous outcrop, have suffered essentially the same degree of metamorphism, and are of approximately the same age,—that is, generally of one period or at most of two successive periods, if of post-Algonkian age; if Algonkian or Archean, they may represent either or both of these pre-Cambrian eras. An exception is made where, as in Adams County, several small prospects in rocks that represent widely diverse geologic time divisions lie so close together and are of such negligible economic importance that the outlining of a separate district for the slate of each age would be an unnecessary refinement.

The table below names the slate districts of the State in order of economic importance, together with their location by counties, the chief producing or shipping centers in each district, the general character of the slate, its geologic age, and the present state of development and quarry activity of the district. The location of the districts is also shown on the key map, Figure 2.

Slate Districts of Pennsylvania

| District | Counties | Centers | Character of slate | Geologic age | State of slate industry |
|--------------------|---------------------------------------|--|--|-----------------------------|---|
| Lehigh-Northampton | Northampton, Lehigh and eastern Berks | Bangor, Pen Argyl, Slatington | True slate, blue-gray, unfading; a little red and green | Middle and Upper Ordovician | Well-developed, active |
| Peach Bottom | Lancaster and York | Delta, West Bangor, Peach Bottom | True slate, blue-black, unfading | Pre-Cambrian | Formerly well-developed, now dormant in Pa. |
| Carbon County | Carbon | Aquashicola Village | True slate, blue-gray, fading and rusting | Middle Devonian | Only a few quarries; abandoned |
| Lebanon County | Lebanon | Nearest center Annville | True slate, blue-gray, slowly fading; some red and green | Middle Ordovician | Prospects only |
| Dauphin County | Dauphin | Nearest center Hershey | True slate, blue-gray, fading | Middle Ordovician | Prospect only |
| Adams County | Adams | Nearest centers Virginia Mills, Bridgeport | Light gray schists, unfading (?); also clay slates, light purple or light slate-gray, fading | Cambrian and Pre-Cambrian | Very few quarries; abandoned. |

In the treatment which follows, the Lehigh-Northampton district (which is by far the largest and most important in Pennsylvania), the Peach Bottom district (a part of which actually extends across the State line into Maryland and is therefore omitted in this report), and the Carbon County district are each considered under a separate heading in some detail. The other three districts—Lebanon County, Dauphin County, and Adams County, are all of such slight economic importance that they have been only briefly treated in a single chapter. The Dauphin and Lebanon County occurrences will probably ultimately come to be recognized as parts of one slate district; as yet the areal continuity of their workable slate beds has not been established, however. No other promising deposits of true slate are known in the State.¹

FUNDAMENTAL DEFINITIONS

For the reader not already acquainted with the terminology of geology or of slate, a few definitions may be helpful. These are given in the briefest form, stripped as much as possible of technical language.

¹ Though quantitative estimates are not possible, the State's slate reserves are far beyond the needs of the next two centuries at present rate of consumption.

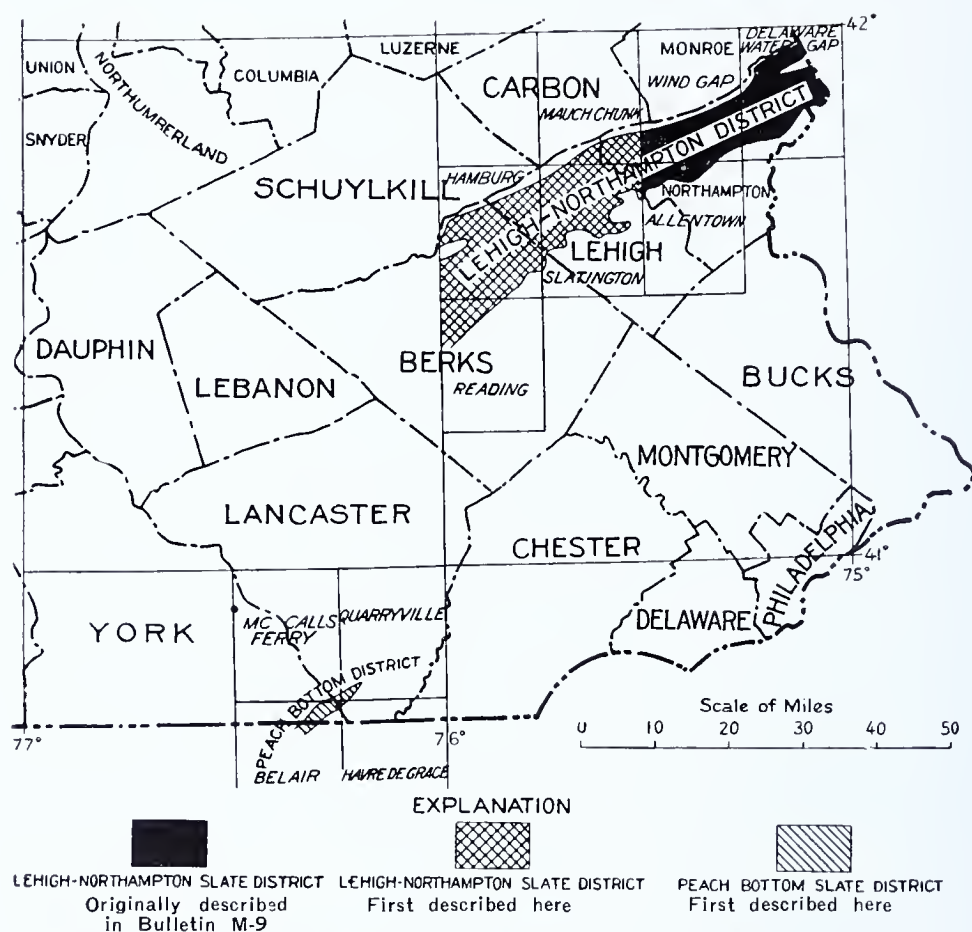


Fig. 2. Outline map of southeastern Pennsylvania, showing slate districts, with counties and quadrangles in which they occur.

Slate. (Thonschiefer, German; ardoise, French)—A survey of the definitions offered by geologists¹ in general shows that the term slate implies four things: (1) that the rock now called slate was originally laid down in beds or layers as a muddy sediment (clay), most commonly in the sea; (2) that it was subsequently buried under other rocks until it reached some depth beneath the earth's surface; then, in response to pressure from the sides, new, sheet-like minerals were developed, arranged with their flat surfaces more or less parallel to each other; (3) that this parallelism of mineral texture gives the slate a tendency to break or "cleave" along accordant, closely spaced, and very smooth planes, oriented without regard to the layers in which the clay was originally laid down; and (4) that the mineral particles of the finished slate are fine and dense.

The essential points mentioned are all embodied in the statement of the Committee on Slate of the American Society for Testing Ma-

¹ Cf., for example: Geikie, Archibald, *Textbook of Geology*, pp. 235-237, New York, 1902; Chamberlin, T. C., and Salisbury, R. D., *Geology*, vol. 1, p. 473, Henry Holt, New York, 1909; Rosenbusch, H., *Elemente der Gesteinslehre*, p. 549, Stuttgart, 1910; Merrill, G. P., *Stones for building and decoration*, pp. 177-178, John Wiley, New York, 1910; Parks, W. A., *Building and ornamental stones of Canada*: Can. Dept. of Mines, Mines Branch Bull. 100, vol. 1, p. 25, 1912; Hirschwald, J., *Handbuch der bautechnischen Gesteinsprüfung*, p. 592, Berlin, 1912; Dale, T. N., *Slate in the United States*: U. S. Geol. Survey Bull. 586, p. 9, 1914; Bowles, Oliver, *The technology of slate*: U. S. Bur. Mines Bull. 218, p. 3, 1922.

terials; this definition, as it is the latest published and represents the summation of the best efforts of scientists and technical men, is the most acceptable, when slightly modified¹:

Slate is a microgranular, crystalline stone derived from argillaceous sediments by regional metamorphism, and characterized by a perfect cleavage, entirely independent of original bedding, which cleavage has been induced by pressure within the earth. Essential mineral constituents are white mica (chiefly sericite) and quartz. Igneous slates, because of their rare occurrence and insignificant commercial importance, are not covered in this definition.

Basic geological terms. In the text of this bulletin various geologic terms must be introduced for a clear technical description. These are explained under the corresponding headings. A few elementary concepts are here presented, however. Mineralogic and chemical terms scarcely merit special explanations, as anyone interested in the mineralogy or chemistry of slate must concern himself first with fundamental studies in these respective sciences.

"Sedimentary" rocks are rocks laid down in "layers," "beds" or "strata," most commonly under water. "Bedding planes" are the planes of bedding or strata. Sedimentary rocks may be "solid," "consolidated", or "bed" rock (such as limestone, sandstone, or shale) or they may be "uncemented," "loose" or "unconsolidated" (like gravel, mud, or sand), depending upon the degree of cementation of the particles with each other.

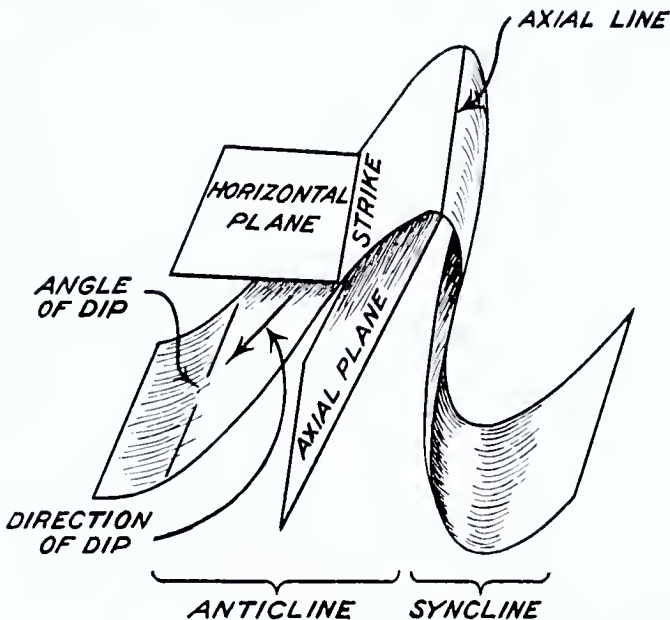


Fig. 3. Diagram illustrating the application of common geological terms to folds.

¹The full definition differs from the one given in that the second sentence is expanded and reads: "Essential mineral constituents are white mica (chiefly sericite) and quartz; prominent accessory constituents are black mica (biotite), chlorite, and hematite. Minor accessory constituents are carbonates, magnetite, apatite, clay, andalusite, barite, rutile pyrite, graphite, feldspar, zircon, tourmaline, and carbonaceous matter." The writer does not believe that the listing of accessory constituents, many of which may be absent from any particular specimen, is justified in a scientifically exact definition; he also takes exception to the mention of hematite and black mica as prominent constituents since both are almost wholly lacking in many commercially important slates.

Sedimentary rocks are often compressed from the sides through what may be loosely described as shrinking of the crust of the earth; how this shrinking is brought about is, for the present purpose, beside the point. It has the well-recognized effect, however, that the layers or bedding planes are wrinkled or thrown into "folds." These folds are described as "anticlines," if convex upward, or "synclines," if convex downward. Their sides or slopes are "limbs." The plane which divides equally the angle between the two limbs of a syncline or anticline is the "axial plane"; its intersection with any given bed is the "axial line" or "axis" of the fold. If the axial line goes downward in a certain direction, the fold is said to "pitch" in that direction. If the axial plane is horizontal or nearly so, the fold is said to be "recumbent."

In geologic descriptions, when giving the positions or attitudes of beds, where, on account of folding they are inclined planes, a simple mode of presentation may be followed. A horizontal reference plane is made to intersect with the bedding plane to be described. The horizontal line of intersection of the reference plane with the bedding plane in question is called the "strike;" the position of the strike is given with regard to true north,—for example, "Strike N.23°E.," which means, 23 degrees east of north. An imaginary line is then drawn *down* the bedding plane, at right angles to the strike line; this is the dip line. Its position in space is given by stating the horizontal direction of its *downward* inclination, again with regard to true north, and the vertical angle which the dip line makes with the horizontal reference plane. Thus, a possible value consistent with the example of strike given above, would be, "Dip 15°, N.67°W.". Since, however, the dip is, by definition, taken to be at right angles to the strike, the figure 67 may be arrived at by subtracting the strike reading (23°) from 90°; hence, 67 can well be omitted from the description. The location in space of the bedding plane is therefore accurately expressed by "Strike N.23°E., dip 15°N.W."

Where the side compression of the earth is severe enough to break the layers or where, for various reasons, the strata are pulled apart, a "fracture" results. Should the beds on opposite sides of such a fracture move relatively with regard to each other, so that those on one side of the fracture no longer match up with those on the opposite side, the rocks are said to have been "faulted." The plane along which the faulting takes place is the "fault plane." The dip and strike method explained above for bedding planes may also be used for describing the attitude or position of fault planes. Indeed, any plane surface that is not horizontal has a measurable dip and strike which may be used for describing its attitude in space.

If in a vertical section, taken at right angles to a fault plane, the overhanging or "hanging" wall of the fault appears to have moved down the dip of the fault plane relative to the opposite wall, the fault is said to be "normal." If the opposite or "foot" wall has moved relatively down, the fault is a "reverse" (sometimes also called "thrust") fault. Fault planes that are vertical can obviously not be regarded as either normal or reverse, since there is no true hanging or foot wall.

"Cleavage" is the structural feature essential to all slates, which gives the slate its capacity to break along numerous closely spaced,

parallel, smooth planes. The property is dependent on the orientation of platy minerals, as already pointed out in defining slate. These closely spaced planes of parting are "cleavage planes." Like bedding planes and fault planes, cleavage planes have measurable dips and strikes.

"Joints" are also planes of parting. They are similar in appearance and generally also in origin to cracks that form in walls or foundations through various causes such as subsidence, simple compression, heat expansion, or sudden shocks. They differ from cleavage planes in that they (1) are almost always more widely separated from each other and (2) are not dependent on parallel orientation of mineral particles.

COMPOSITION OF SLATE

The chemical and mineralogical composition of slate, while ideally distinct from that of other rocks, actually grades into related forms. Thus, some slates, such as those of Carbon County, are closely related to shales and may therefore be called clay slates; others, like those of the Peach Bottom district, are almost schists and pass into the latter rock type by imperceptible gradations. Hence there are wide variations comprised within the term "slate", which make any general description unsatisfactory.

Since the line demarking slate is thus highly variable, only a very general description of the chemical and mineralogical composition, together with the petrographic appearance of slate, will be given here, leaving a more detailed discussion for the sections describing the slates of individual districts. What follows may serve as background for a description of other features, such as megascopic structures or use factors common to most or all slates.

MINERALOGICAL COMPOSITION AND TEXTURE

The chief mineral constituent of almost all slates is sericite, white mica. Dale interprets Renard's computation of numerous mineralogical analyses of French slates¹ as giving the following round numbers for mineral composition, in order of importance:

| | |
|-----------------|------------------|
| muscovite | 38 - 40 per cent |
| quartz | 31 - 45 |
| chlorite | 6 - 18 |
| hematite | 3 - 6 |
| rutile | 1 - 1½ |

This order is also thought to hold especially with respect to the first three constituents, for most of the American slates examined by the writer of this bulletin. However, there are noteworthy exceptions to the proportions given. Further, a carbonate mineral, apparently a form of calcium magnesium iron carbonate isomorphous with siderite, is a very common chemical constituent, notably in the slates of the Lehigh-Northampton district and in those of the Carbon County district. Kaolin is present in all of the less highly metamorphosed slates and carbon (graphite?) is a very common constituent, especially in gray and black slates. There are also in Pennsylvania slates noteworthy

¹ Dale, T. N., *Slate in the United States*; U. S. Geol. Survey Bull. 586, p. 19, 1914; Renard, A. F., *Recherches sur la composition et la structure des phyllades ardennais*; Mus. roy. hist. nat. Belgique, Bull., vol. 3, pp. 230-268, 1885.

amounts of magnetite, limonite, pyrite, biotite, feldspar, zircon, tourmaline, and andalusite. In addition Dale¹ lists, as occurring in some slates, ottrelite, staurolite, garnet, sphene, anatase, hornblende, epidote, apatite, gypsum, pyrophyllite and talc, though none of these was observed in Pennsylvania slates examined by the writer.

Slates are generally very finely granular rocks, individual mineral grains being rarely visible to the naked eye. The component minerals fall into three groups. The first is represented by more or less hair-like, lath-like or platy minerals, with their longer dimensions parallel; these convey the property of the cleavage to the slate, and they preponderate in all slates with well developed, smooth cleavage planes. Of the prominent constituents, sericite, chlorite, some of the quartz (secondary quartz), and some of the biotite fall into this group. The second group consists of minerals forming more or less equidimensional or rounded grains, generally not conspicuously elongated in any one or two directions or, if so, showing no pronounced parallelism in arrangement of longer dimensions. This group includes much of the quartz, as well as the carbonate mentioned above, feldspar, magnetite, zircon, andalusite, some chlorite, and some biotite. The third group consists of minerals showing a scattered or "clump-like" distribution and occurring largely as inclusions in other minerals; here belong especially graphite, rutile, limonite, some of the carbonate mineral, and some of the pyrite.

Since the minerals of Group I are in large part platy, they show elongation when the section in which they are examined is cut at right angles to this elongation, but platy or approximately equidimensional forms when cut in the plane of the plates.

CHEMICAL COMPOSITION

For a detailed discussion of the chemical composition of slate, the reader is referred to the sections describing the slates of individual districts. In general², slates are rocks that are high in alumina (averaging between 12 and 26 per cent, or, say, about 20 per cent); compared with sandstones, are relatively lower in silica (average 35 to 59 per cent); and bear the following per cents of lesser constituents:

| | |
|-------------------------------------|-----------------------|
| CaO | 0.14 - 17.75 per cent |
| MgO | 1.07 - 5.47 |
| Na ₂ O, K ₂ O | 0.53 - 5.98 |
| CO ₂ | 0.11 - 11.81 |

Average values may be thought to lie about midway between the extremes given.

In addition to the elements and compounds listed, FeO, Fe₂O₃, TiO₂, MnO, BaO, Li₂O, P₂O₅, SO₃, ZrO₂, H₂O, and C are generally present³.

Much of the silica is combined with alumina and oxides of alkalis or alkaline earths to form mica and chlorite molecules. The carbon dioxide is combined with calcium, magnesium, and ferrous oxides to form the problematic carbonate mentioned as a common mineral constituent.

Attention should also be directed to the preponderance of potassa over soda in the typical analyses.

¹ Op. cit., p. 18.

² Hirschwald, J., *Handbuch der bautechnischen Gesteinspruefung*, Gebr. Borntraeger, Berlin, 1912, pp. 601-606.

³ Dale, T. N., op. cit., p. 23.

ECONOMIC GEOLOGY OF SLATE

GENERAL SUMMARY

DELETERIOUS FEATURES

The geologic features deleterious to slate quarrying may first be briefly summarized.

A heavy overburden, either of unconsolidated glacial till or river deposits or of partially disintegrated slate, makes stripping operations prohibitively expensive. The overburden is discussed below (p. 13).

In those slates where there are variations in composition from bed to bed, any irregularities in the character or sequence of the beds may be unfavorable to quarry operations. Thus "ribbons" and "hard rolls" (p. 15) are frequently objectionable, though not always seriously so. Siliceous "knots" and graphitic "flakes" (p. 17) are deleterious.

Certain irregularities in the attitude of bedding or of cleavage are undesirable. In general, gently dipping beds are less suited to quarrying than vertical ones. Curved cleavage (p. 30) and false cleavage (p. 35) are serious disadvantages.

Faulting of all sorts (p. 27) is harmful. Closely spaced joints, especially when intersecting the grain at other than right angles, are troublesome in quarrying (p. 39).

Finally, excessive quarry water necessitates costly pumping and introduces other dangers (p. 63), though a moderate amount prevents the slate from becoming brittle.

THE IDEAL SLATE QUARRY

The conditions most favorable to successful slate quarrying, on the other hand, are as follows: An ideal quarry should have but little overburden of glacial material, river deposits, or disintegrated slate. It should be supplied with a moderate amount of water. There should be few or no conspicuously siliceous or carbonaceous beds and no "knots" or carbonaceous "flakes". The most desirable condition is one in which the beds are essentially uniform in composition throughout the sequence. The strata should be nearly vertical and with a constant dip. The cleavage planes should dip at a low angle to the bedding and, preferably, at a low angle to the horizontal as well, so as to facilitate quarrying. Faults and false cleavage should be lacking. Ideally the beds should strike at right angles to the grain and parallel with the cleavage. Jointing should be regular and preferably of one system, the strike being parallel with that of the beds and the dip forming an angle of 90° with the cleavage dip.

TOPOGRAPHY

Steep slopes present advantages and disadvantages. Where the slope is uphill from quarry to railroad spur, the haulage of the quarried slate is expensive. If the slope is downhill, gravity aids in transportation. A steep slope may also form a natural quarry face, permitting quarrying with only a small amount of cleaning of the face before taking out slate, instead of the elaborate and costly operations of stripping, cleaning and the like that usually precede actual quarrying, where the surface is flat.



A. Heavy overburden at Blue Ridge quarries, Slatington.



B. Glacial overburden beneath waste pile, Consolidated-Star quarry, Bangor.

OVERBURDEN

In a few places, especially in the channels of streams, the fresh slate appears at the very surface. Generally, however, some material has to be removed before usable slate is reached.

Most commonly a "rock" overburden—that is, an appreciable quantity of bedrock, which, because of decay or unfavorable structural features, has to be removed by actual quarry methods—is prohibitive to economical quarrying. No quarries are opened if it is known in advance that much solid waste rock will be taken off before acceptable slate is reached. Hence, the only overburden discussed in what follows is one composed of unconsolidated deposits—clay, sand, and gravel, or mixtures of these.

A thick cover, even though only of unconsolidated materials, makes quarrying expensive, necessitating large-scale stripping operations with shovel, drag-line, or hydraulic methods. Further, after the pit is dug and quarrying is begun, rocks from the sides may easily slide or roll into the opening, so that cribbing or other protective measures have to be employed.

An overburden is due either to material transported by stream or glacier and laid down upon the slate or to the gradual development of soil in place through the surface decay of bedrock. In the slate districts of east-central Pennsylvania the former class of overburden predominates, and glacial debris is conspicuous in many places, but in the Peach Bottom district, which lies south of the farthest advance of the ice, rock decay is the only noteworthy manner in which an overburden is formed, except in the stream bottoms, where alluviation may cover the bedrock. Even in the east-central Pennsylvania region the slate has in places been sufficiently weathered to necessitate some cleaning off of the bedrock surface before the fresh slate is reached.

If the overburden is of glacial origin it consists either of clay set with boulders of varying sizes or of bedded gravel, sand, and clay. Stream deposits also consist of similar bedded material. Weathering of the slate yields clayey matter bearing chips and flakes of slate, the proportion of slate becoming progressively greater in depth until unweathered rock appears.

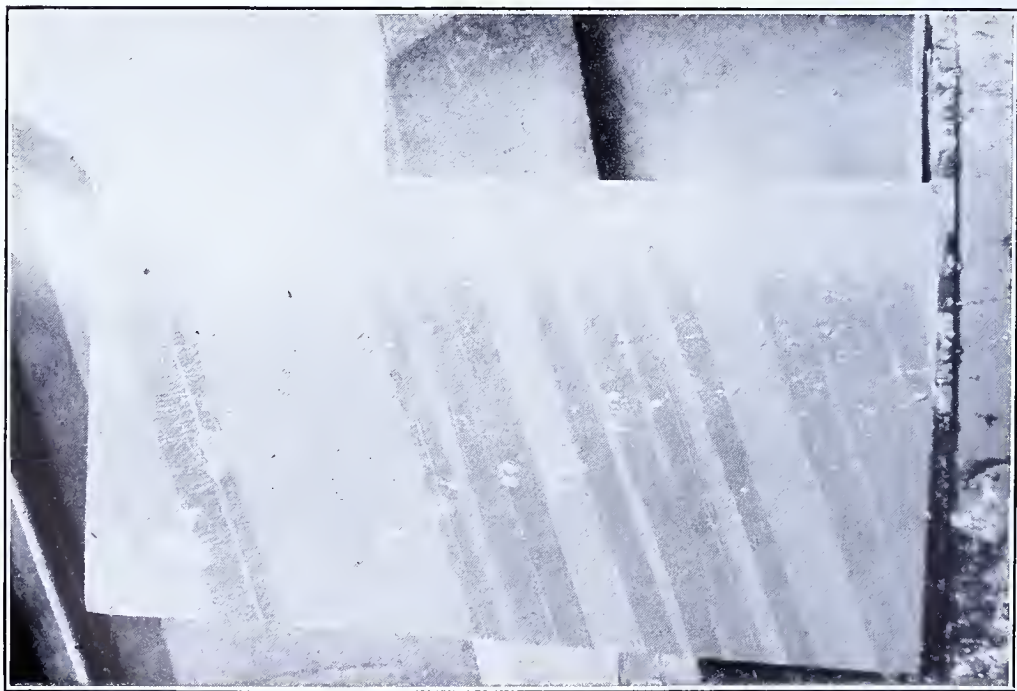
Other things equal, a glacial cover is a favorable indication because the advancing ice generally stripped the weathered slate from the bedrock surface, leaving fresh, marketable slate below. To a lesser extent this statement also applies to an overburden composed of stream-laid gravels. Conversely, if the region in question has not been glaciated or eroded by streams, surface decay will extend into the slate bedrock to varying depths, the change from soil to solid rock being gradational. In such cases, even at appreciable depths, the slate often appears at first glance to be usable; but, upon quarrying, it is found to bear structural flaws and poor color, due largely to penetration by descending water.

VARIATIONS IN BEDDING COMPOSITION

Though possessing a general similarity in physical and mineralogical characteristics, slates vary greatly in detail both in composition and structure. These variations are reflected by differences in workability and use. In a broad way the slates from one district have characteristics which distinguish them readily from those of another. Obviously the slate which possesses certain colors or other desirable qualities will



A. Typical banded hard slate, from lowest member of the Martinsburg formation; the block is 2.5 feet wide.



B. Soft slate, showing alternating carbonaceous and sericitic banding.

have preference over others, and therefore production from one district may be favored temporarily or permanently. For this reason some attention must be paid to weathering, strength, and other qualities; in describing the slate of each region, these qualities are discussed under the proper headings.

In addition to differences in the character of the slate from certain districts, Pennsylvania slates, being of sedimentary origin, also show variations from bed to bed. The changes in sedimentation constitute such an important factor in the slates of the Lehigh-Northampton district that operations are generally directed toward quarrying certain especially desirable beds.

Variations related to bedding are discussed in detail in the consideration of each district. Here also are given representative chemical and mineralogical analyses. Certain outstanding features introduced during deposition of the slate beds and common to the slate in all or at least many of the districts, may be mentioned here.

Sandy beds. Hard, sandy beds, variously referred to as "flint," "sparry beds", and "hard rolls", are objectionable for several reasons. For one thing, where the cleavage crosses them it is likely to form an angle gently inclined to the cleavage in the more argillaceous layers, instead of parallel to and continuous with the latter; indeed, if the layer is rich enough in sand grains, true cleavage may be lacking altogether, the parting planes of the bed being sharp, widely spaced, and irregular, somewhat after the manner of most jointing. At best the cleavage in crossing such a layer is deflected from its true course through a gentle curve. Furthermore, these sandy layers are hard to drill and cut, so that the wear on tools is excessive.

"Ribbons." In the Peach Bottom district all the beds are alike in composition and the slate is uniform in color and texture. In the "soft" slate of the Lehigh-Northampton district, on the other hand, some beds, called "ribbons", are exceptionally rich in carbon. For millstock, where decorative effects are desired, "ribbioned" slate is looked on with favor. For most other uses slate that is free from ribbons is preferred, for the following reasons: (1) since the "ribbons" appear as exceptionally dark streaks, they prevent the use of the slate where a unicolored surface is desired; (2) when subjected to continued abrasion, the "ribbons" disintegrate more rapidly than the rest of the slate, as is well seen in the paving blocks in Bangor; (3) because of their carbon content, the "ribbons" permit the leakage of electricity; hence "ribbioned" slate does not serve well as an electrical insulator.

In the "hard" slate of the Lehigh-Northampton district, "ribbons" or beds distinguished in color from those above and below, also exist, but here the banding, though due in many cases to variations in the amount of carbon, is also caused by differences in silica content and there are thus abrupt and repeated alternations of carbonaceous, siliceous, and originally clayey (now sericitic) layers. The siliceous layers are slightly more, the carbonaceous layers somewhat less resistant to abrasion and chemical corrosion than the sericitic beds, but the differences are not great and the slate splits and weathers on the cleavage plane with essential uniformity. As the separate layers are thin, clear stock is not available and hence there is no reason for wishing to quarry any individual bed or group of beds, the slate being about equally satisfactory in any part of the sequence within wide limits.

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A. Cleavage surface of slab of slate showing carbonate "knots"; from quarry at Aquashicola, Carbon County district.



B. Alternating sandy and slaty layers in Martinsburg formation, showing curvature of cleavage as it crosses the beds. The beds are overturned.

Some of the slates of Adams County which were formerly worked also show color banding similar to the "hard" slates of the Lehigh-Northampton district; in this case variations in color seem to be due chiefly to differences in iron content, though the carbon and lime content also fluctuates from bed to bed; despite the very light color of some of the layers, the calcite content is negligible.

Carbonate "knots". The slate from Carbon County has brown-rusting areas occurring parallel to the stratification; certain beds lacking these areas are preferred, but not enough is known about the details of the sequence to permit the selection of definite beds or areas in advance of opening. These "knots" are discussed further in the section dealing with the Carbon County district.

Calcareous layers. Layers of calcareous matter, generally not exceeding an inch in thickness, are present in some banded slates, especially in the Lehigh-Northampton district. As the cleavage planes are generally completely interrupted or at least sharply deflected in crossing them, such layers present serious difficulties. The only advantage to be gained is in the role they play as horizon markers when the location of a newly opened quarry in the stratigraphic sequence is to be determined, their relation to certain workable beds being known.

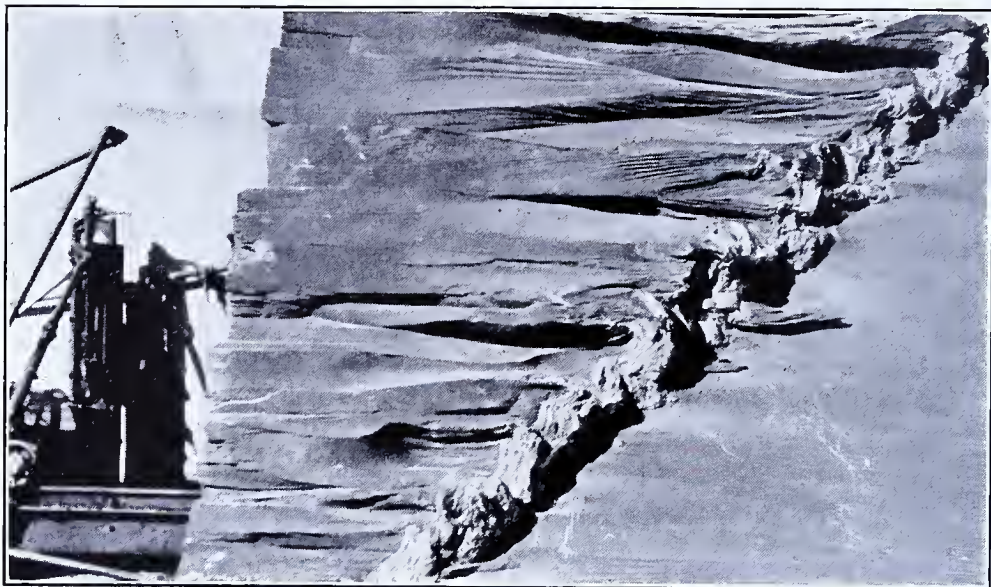
Siliceous "knots". Here and there on the cleavage planes are frequently visible small areas more resistant to abrasion than the rest of the rock. When the surface is polished, such areas appear somewhat darker than the rest of the slate. As proved by microscopic examination, they consist of an aggregate of finely granular quartz, surrounded by the sericite of the slate. They probably represent spots where quartz grains were fortuitously aggregated during the period of deposition¹.

Graphitic "flakes". Not uncommonly in the slate of the Lehigh-Northampton district, a thick bed of clear slate, with the light gray color characteristic of good electrical material, bears irregular masses or "flakes" showing more than the usual carbon content. These carbon "flakes" permit electrical leakage, as was demonstrated by Robert Notvest, formerly of the Structural Service Bureau; Notvest found that the carbon particles form small condensers that facilitate leakage. In the case of Pennsylvania slates, Notvest reached the conclusion that leakage not attributable to moisture is due to the existence of "an excess of carbonaceous substances".²

Weathering along the beds. In some regions, especially in the Peach Bottom district, weathering that takes the form of rusting through oxidation of iron compounds, is observed. Strictly speaking, this is a feature developed later than deposition, yet it is related to sedimentary processes in so far as it is controlled by bedding planes. In the Peach Bottom district the weathering frequently follows what appears to be definitive bedding; other evidence as to the presence of bedding planes is lacking, however, and there is corresponding uncertainty whether the open fracture planes along which "rusting" is so well marked are to be regarded as bedding or joint surfaces.

¹ Behre, C. H., Jr., *Slate in Northampton County, Pennsylvania: Pa. Top. and Geol. Survey Bull. M-9*, p. 98, 1927.

² *Slate for structural uses: The Structural Slate Co., Pen Argyl, Pa.*, pp. 28-29, 1923.



A. Repeated faulting of a calcareous bed, Albion quarry, Pen Argyl.



B. Minutely fractured calcareous bed on northeast wall, lowest level of Northampton quarry, Bangor.

COLOR AND WEATHERING CHANGES

Color of fresh slate. Color is so important a factor in the utilization of slate, especially in roofing and paving, that it merits at least brief consideration here. In selecting slate for architectural uses, it is generally desirable to standardize the color not only of the fresh slate, but also of the weathered material. To date very little progress has been made in this direction in America. A possible reference scale is furnished by the modified form of Ridgway's color chart prepared through the National Research Council.¹

All true slates quarried in Pennsylvania are gray in color, typical of the "slate gray" of common parlance and shading toward blue or steel. On the chart referred to these are most nearly represented by "14^m" or "neutral gray k". Carbonaceous bands are usually a darker variant of the same color. Subdivisions among the grays are not adequately made as yet by color technicians; hence it is impossible to classify the slates more closely. Some of the clay slates of Adams County, now no longer quarried, have a lavender tint approaching "1^d" or "1^d" in color. In addition, there are shaly beds in the middle member of the Martinsburg formation, as exposed in the Lehigh-Northampton district, which have red, green, and purple colors, but as they possess little tensile strength and only poorly developed slaty cleavage, they cannot be split into roofing slate and are only used in crushed or ground form.²

Color changes on weathering. From a commercial standpoint, the "weathering" of roofing slate involves two types of changes: (1) the very slow disintegration, taking place in periods of time measured in many centuries, which ends in the formation of a clay rich in mica and (2) the relatively rapid change in color, usually noticeable in a century or two of exposure. To the latter process, the term "color-aging" might well be applied, to separate it from the later stages of extensive disintegration, which are discussed in a later section of this report.

Almost all slates show a slight change in color after prolonged exposure to the weather, the change varying greatly in intensity, in rapidity, and in the more nearly permanent color finally developed. Slates which change color noticeably on short exposure—say, in three or four years—are called "fading" slates. Some, but by no means all, of the green slates of Vermont may serve as examples. Of those which change more slowly, the red slates become brownish, the black slates fade to a dark gray, and the blue-gray slates become lighter in color or assume a faintly rusty hue. Such gradual color-aging is, as Eckel and Bowles say, not necessarily deleterious; it may actually be favorable, producing a more pleasingly blended tone, if only the change is fairly uniform.³ Naturally, color-aged slates are not readily replaced and a fresh, unweathered slate makes a startling splash of color on an otherwise age-blended roof.

Eckel⁴ states that color-aging is in general least noticeable among the black and gray slates, and that green slates are the most doubtful; Hirschwald, on the other hand, regards the red and green slates as having the most permanent colors, and the black and gray slates as more

¹ Goldman, M. I., and Merwin, H. E., Color chart for the description of sedimentary rocks: National Research Council, Division of Geology and Geography, 1928.

² Recently under the auspices of the Greater Pennsylvania Council studies have been in progress on permanent artificial coloring of Pennsylvania slate.

³ Eckel, E. C., Building stones and clays, pp. 109-110, John Wiley and Sons, New York, 1912; Bowles, Oliver, The technology of slate, U. S. Bur. Mines Bull. 218, pp. 12-13, 1922.

⁴ Op. cit., p. 109.

likely to fade.¹ The difference between the two writers is probably more apparent than real, and depends largely on their differing experience. It has been the present writer's observation that the fading green slates of Vermont are the least permanent. Of other slates, the green, red, and gray colors are generally about equally permanent in the long run, although the soft slates of the Lehigh-Northampton district become very faintly but uniformly paler in color shortly after exposure. The Peach Bottom slates show virtually no color alteration through very long exposure periods. In none of the slates studied, except in the fading green slates of the Vermont region and in the Carbon County, Pennsylvania, district, is the change sufficiently noticeable in the lifetime of the building to merit serious consideration. The original color—that is, whether green, red, or gray—is usually far more important than the slight changes due to weathering.

The causes of marked color-aging in slates are variable. Some changes are doubtless due to the presence of iron sulphides; of these, marcasite oxidizes and hence discolors the slate far more rapidly than pyrite, but it is seldom found. Hirschwald mentions the fading of dark slates through the oxidation of their carbon compounds¹ and presumably also of their carbon. Dale describes Peach Bottom slate which in the earlier weathering stages shows the magnetite masses passing into hematite, and andalusite crystals becoming limonite through oxidation of ferruginous inclusions.²

By far the greater part of color-aging, both desirable and deleterious, however, seems to be due to the presence of considerable carbonate, especially that rich in iron. Generally this is least in the dark gray slates³, but even in these it may be plentiful. Careful investigation by Dale and Hillebrand⁴ showed that much of the mineral matter present in many slates is an isomorphous mixture consisting of the carbonates of calcium, magnesium, manganese, and iron. The presence of the iron may be inferred from chemical analyses, but it may also be demonstrated by brown alteration areas in weathered specimens, which, under the microscope, clearly show as limonite,—a fact first pointed out by Dale⁵. Since cold, very dilute solutions of acids are more effective in attacking carbonates of the bivalent metals than are cold, dilute solutions of the alkalis and alkaline earths, and since, furthermore, the air contains and gives to rain water more acid than basic matter, it is the weak acids that most generally bring about the weathering and color-aging of slate. Dale, Notvest, and Lancaster (at the writer's suggestion) carried out independent studies which bear on this effect⁶, as well as shedding some light on the weathering of slate in general. The approach of Dale was partly petrographic, partly chemical. Those of Notvest and Lancaster were both essentially chemical; these two investigators used solutions so strong as to be wholly abnormal ($1/4$, $1/10$, and $1/20$ normal), and long, continued periods of complete immersion, to produce accelerated "weathering". All such studies showed that, in the case of the Pennsylvania Lehigh-Northampton slates, the first and most conspicuous change was the removal of the

¹ Hirschwald, J., *Handbuch der bautechnischen Gesteinsprüfung*, p. 613, Berlin, 1912.

² Dale, T. N., *op. cit.*, p. 53.

³ Eckel, E. C., *Building stones and clays*, pp. 108-109, John Wiley, New York, 1912.

⁴ Dale, T. N., *op. cit.*, pp. 56 and 140.

⁵ *Op. cit.*, p. 140.

⁶ Dale, T. N., *op. cit.*, pp. 53-55; Notvest, Robt., *The resistivity of slate against acids and alkalis*, p. 6, privately published, 1925; Lancaster, C. L., oral communication.

carbonates of lime and magnesia, and the oxidation of the ferrous carbonate to a limonite, with deposition of the latter. It is this which gives the faint browning or rusting to the slate. The change is most marked in the case of nitric, hydrochloric, and acetic acids; sulphuric acid keeps the iron in solution, presumably as ferrous sulphate, and the effect of alkalis is imponderable. It should be clearly understood that these changes are very slow and essentially not measurable except where "acceleration" is deliberately produced by the use of abnormally strong concentrations of the reagents.

SECONDARY STRUCTURAL FEATURES

FOLDS

Character of folds. The common geologic terms used in describing folds and the position of folded beds have already been defined on a previous page. (See also Pa. Top. and Geol. Survey Bulletin G-1).

Only the most generalized statements can be made as to the folding in the Pennsylvania slate regions. For details the reader is referred to the descriptions under each district and to the corresponding structure sections. In the Peach Bottom district, bedding is so poorly defined that only inferences regarding the structure are possible.

As a rule, the folding is of the "similar" type, with noteworthy thickening on troughs and crests and thinning in the limbs. The folds have pitching axes, with variations in the opening angle between the limbs. There is generally a marked tendency toward northward overturning which varies from a few degrees off the vertical to a nearly horizontal position. Thus, the axial planes at Slatington, in the Lehigh-Northampton district, dip steeply south, whereas those at Bangor, only twenty miles farther east, have been rotated to the horizontal position.

In many places, especially where the axial planes depart from the vertical, the element of pitch may introduce additional complications. Further, with pitching axes and inclined axial planes, the axial lines are curved on the horizontal reference plane, and in at least one instance—that of the flat syncline at Bangor—there is a suggestion that the almost horizontal axial plane has even suffered warping in a vertical direction.

Thinning and thickening of beds by folding. Many beds show variations in thickness due to folding. Illustrations of this fact are most numerous in the quarries of the Lehigh-Northampton district—notably at the Old Bangor, New Peerless, and North Bangor quarries near Bangor and in the Enreka and nearby quarries at Slatington. Quantitatively it is shown by the following table, which represents the measurements of a single bed in different parts of a synclinal fold that is overturned to the north:

Table A

| <i>Thickness of Pen Argyl Gray bed in Albion Quarry, Pen Argyl</i> | | |
|--|-------------|---------------------|
| Depth below surface, feet. | Dip of bed. | Thickness in inches |
| 0 | 27°S | 54 |
| 85 | 28.5°S | 80 |
| 120 | 35°S | 79 |
| 275 | 19°N | 112 |
| 285 | 9°N | 113 |



A. Thickening of big bed at synclinal axis, Eureka quarry, near Slatington.



B. Extreme thickening of beds in fold of hard slate, Edelman quarry, Lehigh-Northampton district.

It is seen that the thicknesses are greater where the dip reverses,—that is, near the axis of the fold.

The extreme of the axial thickening of beds is to be looked for in places where the folding is very flat and where there is a single dominant fold—as in the Old Bangor syncline—rather than a series of folds lying one above the other and with axial planes about parallel, as in the Albion quarry. This might be expected, as the actual length of material available for packing at the synclinal or anticlinal trough or ridge is less when the beds are thrown into repeated close folds, the distance from trough to crest being less.

Moreover, the figures cited in Table A not only suggest a thickening at the axis, but also a greater thickness on the north than on the south limb of the syncline,—a response to thrust from the south. This asymmetrical thickening on the north limb is also shown by the following comparisons between thicknesses in the Old Bangor and Columbia Bangor quarries; the data from the Old Bangor quarry are from the upper or south limb of a northward overturned syncline, whereas those from the Columbia Bangor were obtained on the lower or north limb of the next lower fold; they therefore furnish a comparison between the north and south limbs of comparable structures.

Table B

| Name of bed | Name of quarry | Dip of bed | Thickness, inches |
|----------------|-------------------|------------|-------------------|
| Middle big bed | { Old Bangor | 20°S | 42 |
| | { Columbia Bangor | 44°N | 122 |
| Gray bed | { Old Bangor | 20°S | 34 |
| | { Columbia Bangor | 44°N | 132 |

Greater thickness of beds on the north sides of synclines is to be expected in northward recumbent or tipped folds, especially if the folds rise to the south and have axial planes dipping southward¹.

Interpretation of folded structures. In most of the districts here described, there are no fossils, and the primary sedimentary features from which structure might be inferred, such as cross-bedding and ripple marks, are lacking, or nearly so. Nevertheless, many quarries show folds in which the beds of one limb are clearly inverted: it is obvious therefore, that some method must be used, especially where exposures are few or small, for distinguishing, for example, between beds dipping southward and lying on the north limb of a symmetrical syncline and beds dipping southward but on the south limb of a northward recumbent syncline. The clue to such a distinction is furnished by the cleavage, or plane of easiest parting in slate.

It has long been known that the cleavage in slate tends to parallel the axial planes of the folds and thus to bisect the angle formed by the two limbs. Where the beds dip southward more steeply than the cleavage they must therefore be overturned and on the south synclinal limb; if the cleavage has the steeper dip, the beds are on the north limb. Further, if on the horizontal surface the cleavage trace is parallel with the bedding trace, the axis of the fold is horizontal. But where the cleavage and bedding traces intersect, it is obvious that the fold

¹ See also Behre, C. H., Jr., Observations on structures in the slates of Northampton County, Pennsylvania: Jour. Geol., vol. XXXIV, pp. 490-491, 1926.

itches, and in such cases the relation between strike and dip of bedding and cleavage planes furnishes the clue to the direction of the pitch. These facts are illustrated by Figure 4.

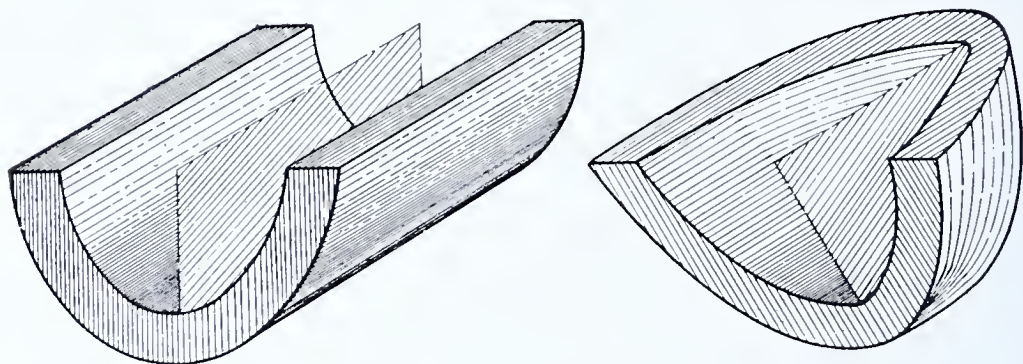


Fig. 4. Ideal relations between cleavage, axial plane, and bedding in symmetrical fold (on left) and in fold overturned to the left and pitching toward the reader (on right); traces of cleavage planes are represented on front and top of models; axial planes also shown, parallel to cleavage.

Method of projecting folded beds. The vertical depth of exposure in any given place in the region studied is so slight that a general method had to be devised for interpreting structures and projecting

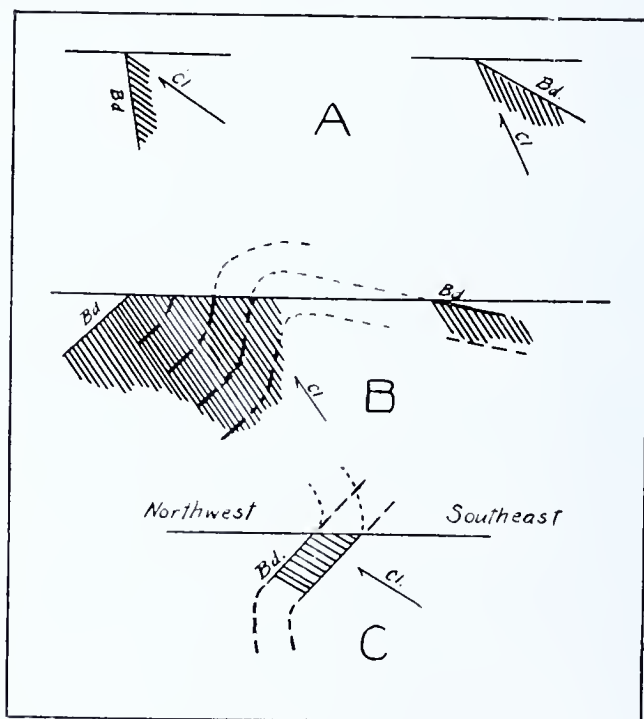


Fig. 5. To illustrate methods of restoring folds on basis of relations between cleavage and bedding. A. Left, beds overturned to left; right, beds normal. B. Restoration of dip of beds with depth. C. Determination of true structure; dotted lines incorrect, dashed lines correct interpretation.

dips. Three principles may be applied. The first is that in general, cleavage approximately bisects the opening angle between the opposite limbs of a fold; or, to put it differently, the cleavage planes are parallel to the axial planes of folds. The second is a corollary of the first, namely, that a dip observed at the surface is duplicated in depth at the intersection of each successive bed with the cleavage plane seen at the surface where the dip was read. The third principle is based on empirical observation: in all of the slate formations of Pennsylvania it happens that the observed normal structure is recumbent or at least tilted folding, tipped to the north. The application of these methods is illustrated by Figure 5.

Economic significance of folds. In some slate deposits the entire thickness of the rock is workable, and, if the other structural features are favorable, exploitation may be carried on anywhere within the slaty member or formation. As far as could be ascertained by a study of the quarries in Maryland, just south of the Pennsylvania line, this applies in the Peach Bottom district. In a general way, it is true also for the "hard" slate belt of the Lehigh-Northampton district. In Carbon County and still more recognizably in the "soft" belt of Lehigh, Northampton, and Berks counties, however, certain valuable beds are especially sought, and the slate above and below is so relatively valueless that removing it is avoided when possible.

Where such selective quarrying is desirable the most important single effect of folding is evidently the difficulty introduced in finding or following a particularly desirable stratum. The approximate position of such a bed is generally known, both stratigraphically and areally, from observations in other nearby quarries. The problem then is to understand how the beds are folded and where on the surface a certain member of the series will appear. Obviously, the more nearly the dip approaches the vertical, the more closely does the line of outcrop approximate the strike. On the other hand, the outcrop of beds that are flat-lying or nearly so is greatly affected by hills, valleys, and other variations in the topography and swings more or less irregularly across the landscape in response to these features.

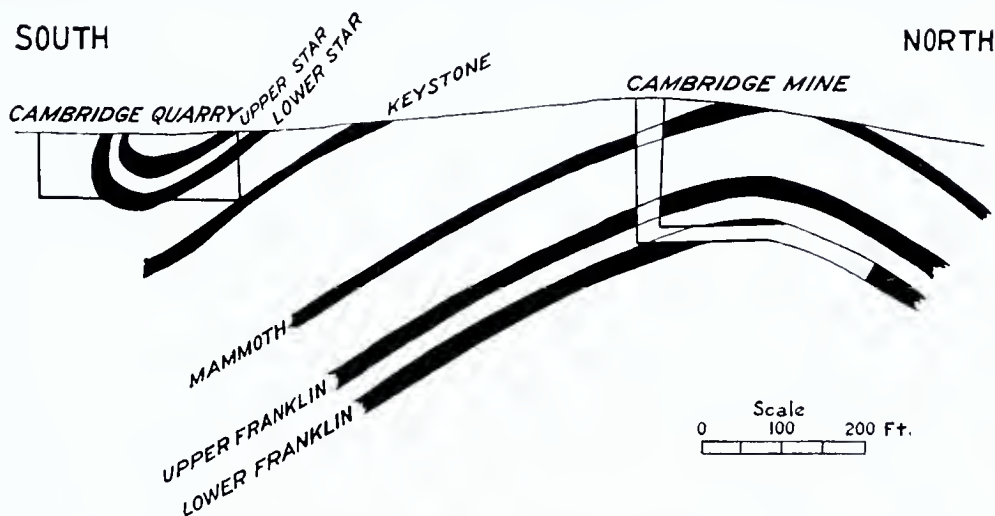


Fig. 6. Section through Cambridge mine at Slatington, Lehigh-Northampton district, illustrating method of following bed down dip by slope mining.

The attitude of the strata also affects the manner of quarry operation after the desired bed is located. Thus at Bangor, where the beds lie flat, stripping and large-seale quarrying are the methods in common use, and extracting the slate of a particularly desirable bed is a very expensive operation because of the surface area that must be opened; examples measure 1000 by 500 feet (Consolidated-Star quarry) and 1200 by 500 feet (Old Bangor quarry). At Pen Argyl, however, the beds are almost vertical and openings can be made relatively small and shaft-like, the greater areal dimensions being the width along the strike; great depth, rather than surface area, is attained. At Slatington the beds are also nearly vertical but show repeated turns at shallow depths; mining, especially the sinking of shafts to the more nearly horizontal crests and troughs of antilines and synclines, has therefore been resorted to, with considerable success (see Figures 6 and 7).

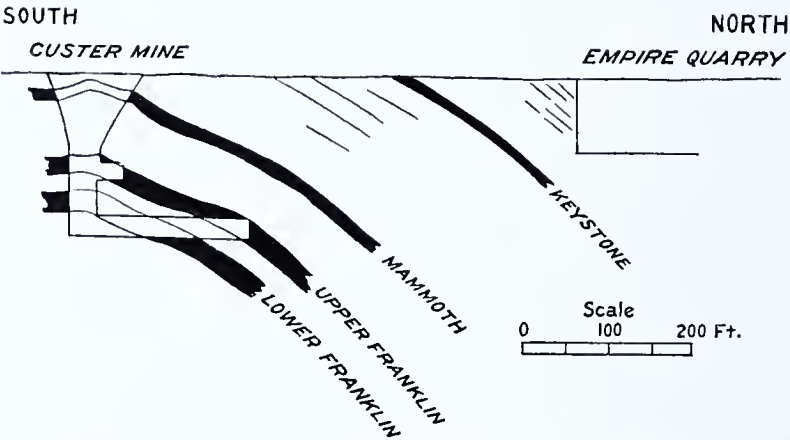


Fig. 7. Section through Custer mine near Slatedale, Lehigh-Northampton district, illustrating shaft approach in mining beds that do not outcrop.

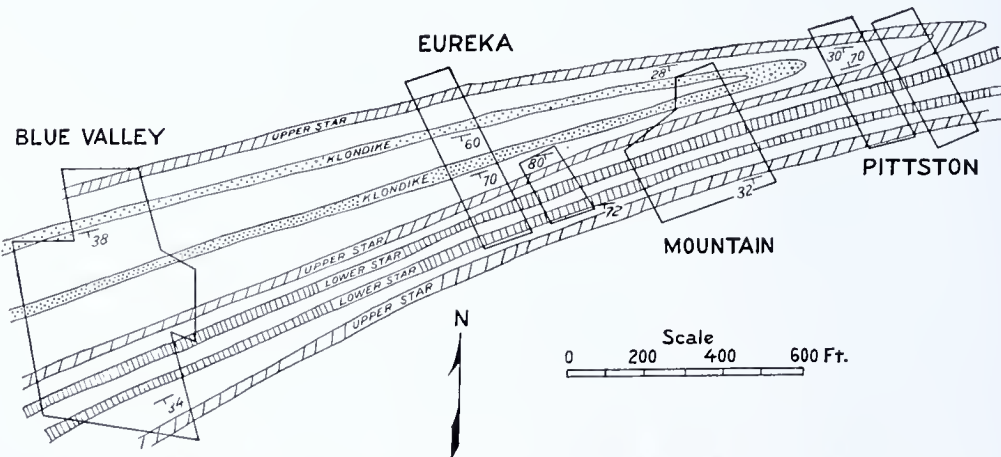


Fig. 8. Sketch map showing effect of pitch at quarries near Eureka, west of Slatington, Lehigh-Northampton district. Three big beds—the Klondike (above), Upper Star, and Lower Star (below)—appear in a syncline, with an antiline, to the south; the syncline pitches west.

Pitch, too, must be allowed for, in considering the availability of a desirable slate bed. Thus, adjacent properties along the strike are not always equally promising. At Eureka, about a mile northwest of Slatington, in the Lehigh-Northampton district, a group of six closely spaced quarries has been opened in a syncline. The fold includes two especially valuable beds,—the Klondike big bed above and Upper Star big bed below. These two beds are exposed in the four westerly quarries but the Klondike bed is not reached by the more easterly operations because of the westerly pitch of the fold (see Figure 8).

The thickening and thinning of beds must obviously be taken into account. Hence, other structural features being the same, it is generally more advantageous to quarry near the crests or troughs of folds than on the thinned limbs; and, if the choice is possible, the north limb of a syncline (or south limb of an anticline) is preferred, for reasons stated above.

FAULTS

On the whole, faults are not conspicuous in the slate, because the easiest adjustment in argillaceous beds is by plastic “flowage” or, if the pressure becomes very great, by recrystallization. In the Peach Bottom district no true faults are known. Within the Carbon County district no faults are known to affect the slaty beds in the region where they have been worked. Only in the Lehigh-Northampton district are faults that cut the slate of noteworthy importance; for a description the reader is referred to the detailed discussion of that region.

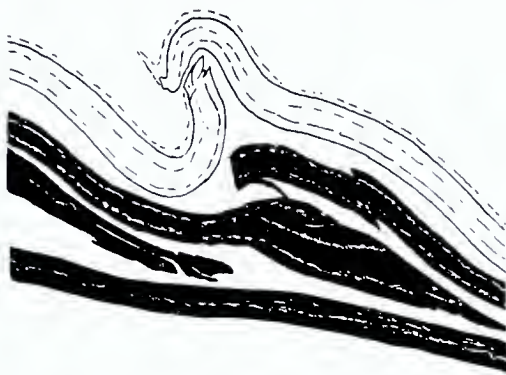
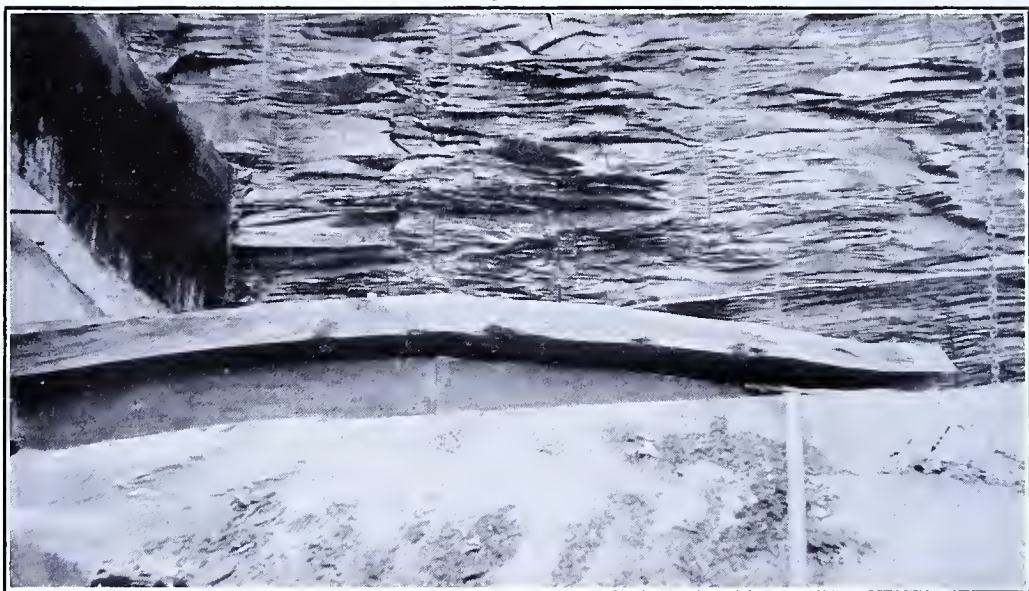


Fig. 9. Drawing of a small thrust fault that preceded cleavage development of the slate; width of block sketched is 12 inches. From mill of West Bangor quarry, Lehigh-Northampton district.

In general, throughout the various slate regions of the Appalachian Mountains, there are two types of faults. The first of these is represented by thrust faults of relatively large horizontal displacement, in which the fault plane is roughly parallel to the plane of cleavage and the axial planes of the folds. The second consists of faults with smaller displacement, the planes of which generally cut the axial planes of folds at high angles; these show chiefly vertical movements and are commonly normal faults, although high-angle reverse faults are also known.



A. Gently curved cleavage; this slab can be used despite the curvature of the cleavage; New Peerless quarry.



B. Relation between cleavage ("split"), bedding, and grain in a block of slate; the surface in the plane of the page is grain. Traces of bedding (B) and of cleavage (A) are visible in the plane of the grain.

CLEAVAGE

Terms defined.—The term “cleavage” has been applied to three different structures in slate. It has been used to designate parting along numerous, close-spaced, and parallel planes that bear no relation to bedding; this is true “cleavage” and the use of the term should be restricted to this feature. The term has also been applied to a tendency to part along small, joint-like openings, more closely spaced than joints, but less so than true cleavage planes, and generally inclined to the cleavage; this, following Dale, may be called “false cleavage.” A third set of fracture planes of which no trace is visible to the naked eye until the slate is actually broken and which is generally at right angles to the true cleavage, is the “grain,” “sculp,” or “scallop” of quarrymen. In this paper the terms cleavage, false cleavage, and grain are used in the senses indicated above (See Figure 10.)

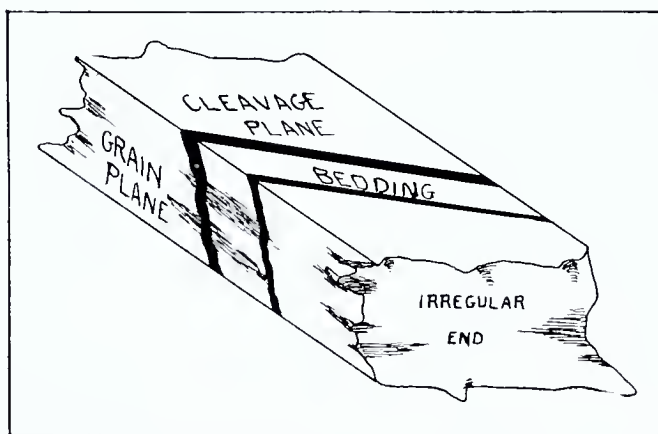


Fig. 10. Structural features in slate, as quarried.

The cleavage plane in slate is the direction of easiest parting and is due chiefly to the arrangement of the individual crystals in the rock.

Origin of cleavage and attitude of cleavage planes. The origin of cleavage is discussed at length in the section on the metamorphism of slate. Loosely stated, the cleavage planes are at right angles to the direction of compression; under the microscope the elongation of the main constituents is seen to be parallel to the cleavage plane, which leads to the inference that cleavage is due to this arrangement.

In general, the cleavage planes are parallel to the axial planes of the folds and to the regional structures. Their position is thus fairly uniform over large areas. Since all of the Pennsylvania slate districts are part of the Appalachian folds, and since the trend of the latter is northeastward, cleavage planes as a whole trend northeast in all the districts here described. The average strike is about N.60°E., with southward dips. There are, however, far greater exceptions in the degree of dip. In the Peach Bottom region it is seldom less than 70° and in cases almost 90°. In the Carbon County district the dip is about 75°S. In the Lehigh-Northampton district it changes regionally, steepening westward: at Bangor it averages about 15°, whereas from Slatington west it is nearer 55°.

Curvature of cleavage. The cleavage planes are not uncommonly curved, sometimes assuming an S-shape, apparently due to added compression after cleavage formation (Fig. 11). This type of curved cleavage is especially noticeable near bedding-slip faults (page 166).

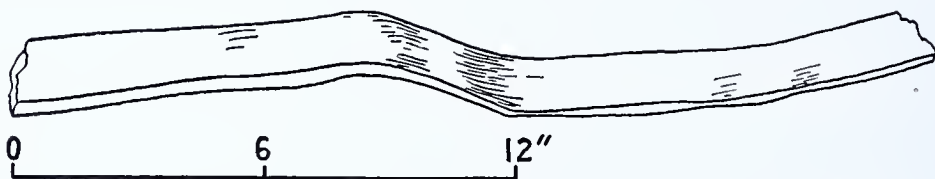


Fig. 11. Gently curved cleavage piece, Cambridge quarry, Slatington.

In addition to the marked cleavage curvature just referred to, there is a tendency, where cleavage planes cross sandy beds, for them to curve slightly. This type of curvature is not induced by deformation after the development of cleavage, but is due merely to the higher angle between cleavage and bedding in sandy beds where mica and chlorite, the cleavage producing minerals, are less well developed than in the typical slate.

In a few quarries the cleavage shows very gentle curvature or changes slightly in angle of dip from top to bottom of the quarry. This is well illustrated in the Albion quarry at Pen Argyl, in which each level is developed on a gentle curve; indeed, despite the predominant south dip of cleavage, the cleavage planes at the north end of the quarry floor actually dip northward at very low angles.

Effect of cleavage attitude on quarrying. Quarry methods are determined largely by the attitude of cleavage. Thus, in the eastern part of the Lehigh-Northampton district, the flat cleavage planes make possible the use of channelling machines; not only is it easy to run the channeller on a track, but the blow is downward and assisted by gravity. In the Slatington region, however, where the cleavage dip is steeper, the channeller can only be used under somewhat unusual conditions,—for example, in freeing the lowest or “key” block; here instead much of the work can be done by drilling, because the drill can be more easily mounted so as to drive horizontally. Focht¹ has pointed out that even the wire saw, which is a far more flexible cutting device than the channeller, is operated with more difficulty where the cleavage dips steeply. In general the quarry operations are complicated by steeper dips.

Curved cleavage, irregular cleavage, or a tendency to break across the cleavage planes (“curl”, “slip cleavage”, “false cleavage”) are of course deleterious factors.

Surface deflection of cleavage. Where the cleavage planes stand at a steep angle to the horizontal on a sloping surface they are likely to show the effect of creep,—the very slow downhill movement of the rock at the surface of the ground. This sometimes leads to an erroneous impression as to the direction of the dip of cleavage. By Dale this was mistakenly attributed to the dragging effect of the ice sheet

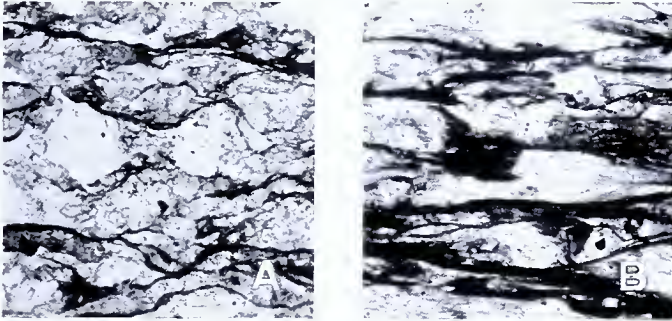
¹ Focht, Doster, Discussion: Behre, C. H., Jr., Geologic factors in the development of the Eastern Pennsylvania slate belt: Am. Inst. M. M. Eng., Trans., vol. 76, pp. 410-411, 1928.

of the Great Ice Age¹, but since cleavage is in many places dragged in the opposite direction to that in which the ice moved the explanation first given is more acceptable.

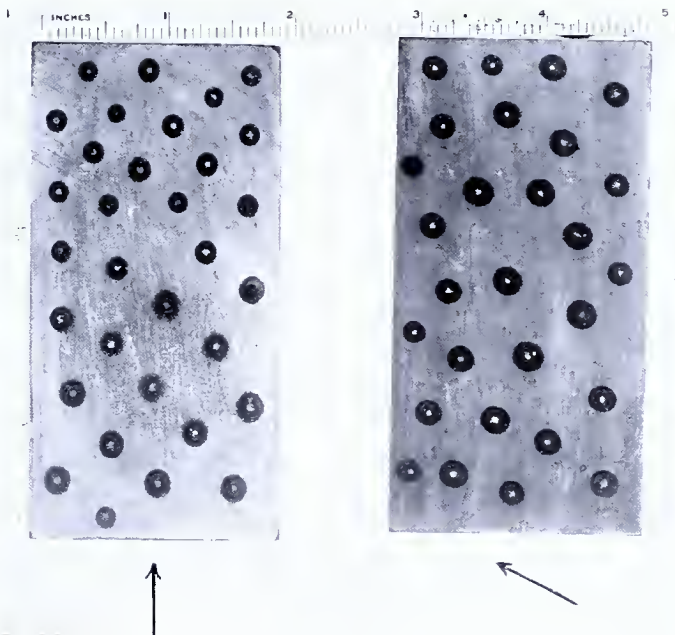
GRAIN

Description. In all of the slate studied by the writer, there is a second direction of ready fracture far less marked than that of the cleavage. This is the "grain", "sculp", or "scallop" of English and

PLATE 7.



A. Photomicrographs of thin sections of coarse slate from Lehigh-Northampton district: (A) cut at right angles to cleavage and grain, to show absence of marked parallelism of hair-like lines (mica flakes) and (B) cut in the plane of the grain to show conspicuous parallelism of mica flakes.



B. Cleavage surfaces of two blocks of slate showing melt figures of Jannetaz; arrows indicate direction of elongation and hence also of grain.

¹ Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, Plate XVII (opp. p. 104), 1914.

American authors, the "longgrain" of the French. Typically two opposite sides of a block of slate, as quarried, are bounded by planes developed along the grain, two of the remaining four sides being formed by cleavage planes (see Figure 10). Though not clearly indicated by megascopic structural features, yet the grain plane can be determined if carefully sought for. Indeed, Dale describes a more or less obscure striation on the cleavage surface as indicating grain direction¹; this may be seen on many Pennsylvania slates.

The grain planes differ from planes of false cleavage, with which they are sometimes confused, in two ways. One of these is that they are not sharply defined and virtually unwarped planes, but are more or less curved and irregular surfaces, which can be treated as planes only when generalized. Yet, broadly viewed, the grain surfaces present so remarkable a constancy in direction and dip that they must clearly be regarded as a definite structural feature. The other outstanding distinction lies in their differing orientation with regard to the dominant axes of the folds. False cleavage is generally approximately parallel in strike with the fold axes. Grain, on the other hand, commonly strikes at right angles to these axes and to the cleavage. Leith points out the local similarity between grain, as the word is sometimes used, and false cleavage. Dale clearly distinguishes grain from "slip" cleavage.¹

Origin. The explanation of grain has been attempted by early experimenters, including Daubree, Renard, and others, whose work has more recently been summarized by Dale. Both Leith² and Dale³ attribute grain to the arrangement of the mineral particles in the slate. Both are of the opinion that grain direction is parallel to and determined by the greatest dimension of some of these mineral constituents.

That grain must be related to mineral orientation or to some other vector properties of the rock may be shown in several ways. Electrical tests amply demonstrate the greater conductivity of the slate parallel to the grain. (See page 75.) The writer has repeated the heat conduction experiment, using Pennsylvania slates, with the same results as originally obtained by E. Jannetaz. In this the cleavage surface is covered evenly with a thin coat of wax. The point of a red-hot needle is then brought perpendicularly against the surface of the stone. The heat, transmitted largely through the slate, melts the wax, and a roughly circular area is outlined by melting and remains as a slight depression after cooling. When this experiment is repeated several times and the forms of the resulting melt figures are examined, it is seen that they are ellipses, rather than true circles (see Plate 7, B). The direction of their greatest elongation is parallel to the grain.

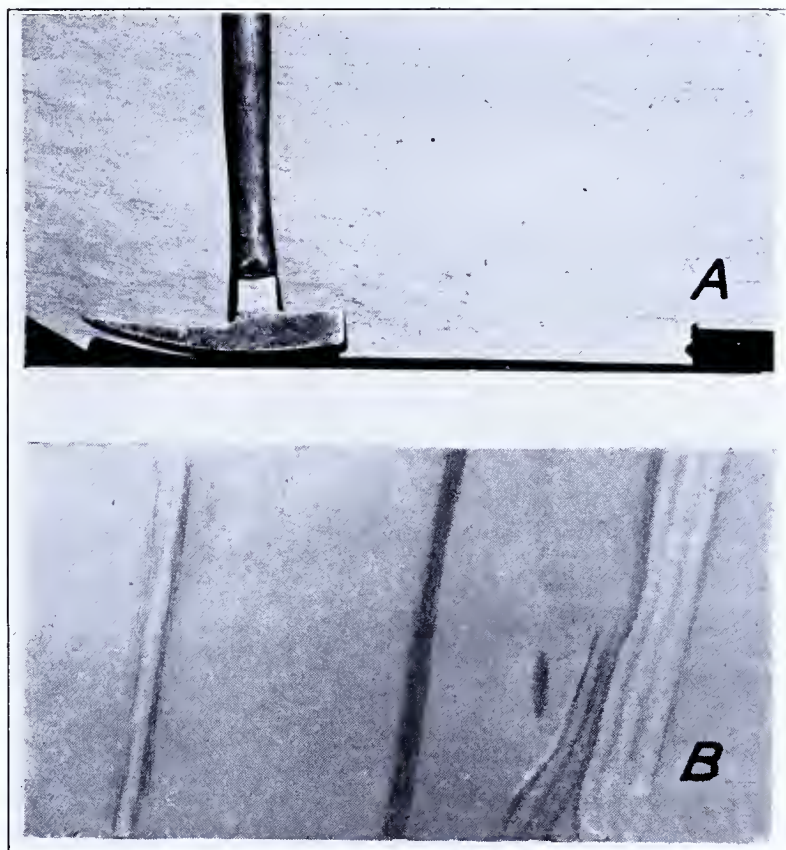
A study was made to determine the relation between the longest dimensions of minerals in slates and the grain direction. Oriented sections of "hard slate" from the Lehigh-Northampton district showed that sericite and quartz grains exhibit marked elongation parallel to the grain. In the case of sericite the ratio of length to breadth in the cleavage plane averages 3:1. The rutile needles in the body of the rock were also especially well oriented, with long axes in the grain direction. Similar observations were made on sections of a big bed from the Al-

¹ Dale, T. N., *Slate in the United States*; U. S. Geol. Survey Bull. 586, p. 41, 1914.

² Leith, C. K., *Rock cleavage*; U. S. Geol. Survey Bull. 239, p. 133, 1905.

³ Op. cit., p. 41, 1914.

PLATE 8.



A. Cleavage surface of roofing slate from Peach Bottom district; the longer edges being parallel to the grain, note faint striations on surface which indicate grain direction.

B. Irregularities of bedding in roofing slate from Bangor; note widening of one dark bed.

bion quarry, in the eastern part of the Lehigh-Northampton district. The most marked elongation in the grain direction was observed in sections made from a "hard roll" (sandy slate bed) at Pen Argyl (see Plate 7, A). In oriented sections of slate from the New Diamond quarry near Pen Argyl, the texture was very uniform and there was nothing to suggest elongation except in the arrangement of the longest dimension of the quartz grains. It thus appears that grain in slate is determined by parallelism of the longest dimensions of mineral particles, in much the same way that cleavage is due to parallel orientation of the flat sides.

Strike and dip. In the experience of the writer, grain is generally at right angles to cleavage. Figures given by Dale¹ do not indicate marked constancy in the trend of grain in the Vermont-New York slate belt. In Pennsylvania slates, on the other hand, the grain planes show remarkable regularity of orientation. This is illustrated by Figure 12, which represents the direction of grain strike in 71 quarries of

¹ Dale, T. N., The slate belt of eastern New York and western Vermont; U. S. Geol. Survey 19th Ann. Rept., part III, pp. 218-221, 1898.

the Lehigh-Northampton district. The dips observed are generally vertical or nearly so. Thus, of the 71 observations figured, only 28 varied from the vertical, and none of these represented a dip of less than 70° . It must be noted, however, that observations of the grain "plane" are necessarily generalized. They are never subject to contact measurement, since the grain fracture is always wavy.

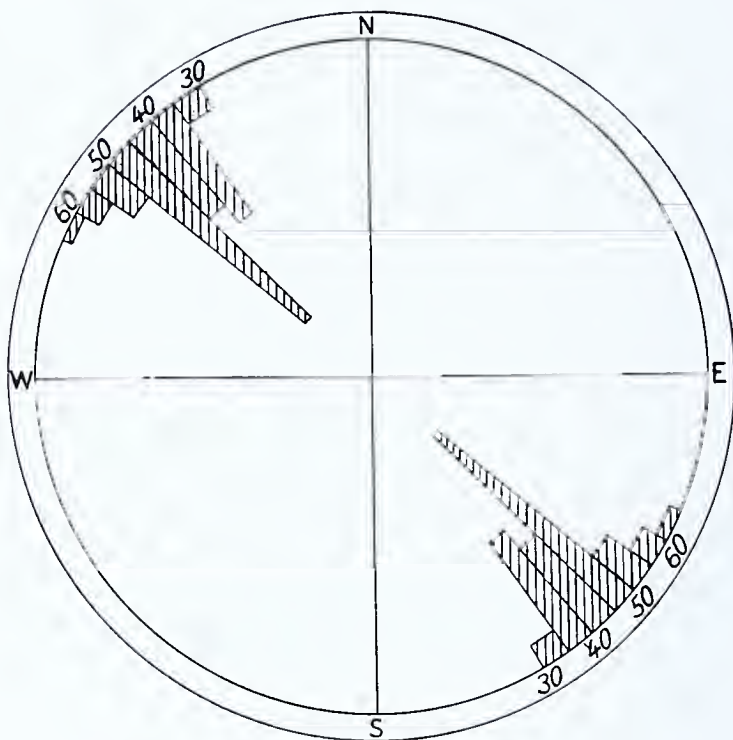


Fig. 12. Azimuth chart of strike of grain as recorded in 71 quarries of Northampton County, selected at random. The numbers indicate degrees in azimuth west of north (east of south) in bearing of grain strikes. The relative lengths of the inward extending lines show the relative numbers of observations yielding the indicated strikes.

The question may be raised, why should the grain plane retain a constant orientation in a region where even the cleavage shows irregularities from place to place. The answer is twofold. Firstly, the grain, as stated above, is not strictly a smooth surface, subject to contact measurements; hence slight variations are not noticed. Secondly, the cleavage plane commonly approaches the horizontal, while the grain plane generally stands vertical. In most regions slaty rocks have been deformed at least slightly subsequent to the origin of the cleavage. In such instances, if, after the development of cleavage and grain, the second compressive force varied ever so slightly from the direction taken by the compression responsible for cleavage position, the gently inclined cleavage planes were given a markedly different strike direction; on the other hand, the nearly vertical grain suffered only a small change in strike.

Economic importance of grain. The grain is of great importance in quarrying slate. In most operations it furnishes the second direction along which the rock is mechanically split apart, the cleavage

being the first. Roofing slate is usually cut so that the longer sides of the slate are in the grain direction, in order to reduce the breakage.¹

The practice of cutting or wedging the slate parallel to the grain makes for a marked orientation in quarry dimensions. This is readily recognizable in all of the Pennsylvania slate quarries. Since all are in the belt of Appalachia folding and since the axes of such folds trend northeast, the openings usually have one major dimension in the northeast direction; the other is almost without exception at right angles,—that is, in the direction of the grain.

FALSE CLEAVAGE

Description.—"False" cleavage ("slip" or "fracture cleavage" of authors²) is a tendency to break along very closely spaced, frequently short and seldom conspicuous joint-like fissures, with planes which are generally at right angles to the cleavage. Such fractures result in the formation of slender pencils of slate, bounded on the top and bottom by cleavage, on the sides by false cleavage. Locally several intersecting sets of false cleavage may be developed,³ but in the experience of the writer the usual occurrence is in one set only, and there are grounds for doubting the correctness of statements to the contrary.

Dale⁴ rightly draws attention to the distinction between false cleavage and jointing. Jointing may occur in two directions, the bisectrix of the dihedral angle between intersecting joint planes being a direction of maximum or minimum stress, whereas false cleavage planes, like planes of true cleavage, have their strike at right angles to the maximum stress direction. This of itself, however, may not serve to distinguish false cleavage from jointing, since the stress directions are not always clearly defined.

False cleavage is commonly indicated by fine lines or very narrow, open fissures which are discernible on the cleavage surface of the slate. It is frequently associated with a visible folding of the cleavage planes and when such folds are present and are crossed by joint-like fractures parallel to the axes of the folds, the presumption is strong that the fractures are false cleavage. Under the microscope the false cleavage planes are seen to be due to extreme plication of true cleavage planes. In approaching a zone of false cleavage, the shreds of muscovite and chlorite show some curvature, and, instead of appearing as straight lines (the condition in normal slate cut at right angles to the cleavage plane), become undulating. The orientation of these minerals in the undulatory strands is well marked because one limb of any single tiny undulation is dark under crossed nicols, while the other is relatively light. As the folding of the cleavage strands becomes progressively more intense, the strands tear apart along a line more or less at right angles to their length and an open, joint-like fracture develops; this latter is true fracture cleavage ("false cleavage"), the flexings being incipient stages of fracture cleavage, to which Van Hise's term fissility might be applied. An illustration is furnished by Figure 13.

¹ Bowles, Oliver, The technology of slate: U. S. Bur. Mines Bull. 218, p. 10, 1922.

² Dale, T. N., op. cit., p. 37, 1914; Leith, C. K., Rock cleavage: U. S. Geol. Survey Bull. 239, p. 119, 1905.

³ For example, Spurr, J. E., The stratigraphic position of the Thomson slates: Am. Jour. Sci., 3d. ser., vol. 48, p. 164, 1894.

⁴ Op. cit., p. 39, 1914.

So far as noted by this writer, the strike of false cleavage planes approximates closely or is in actual agreement with that of the true slaty cleavage, except under one condition, noted below. The strike is hence generally also parallel to the axes of folds.

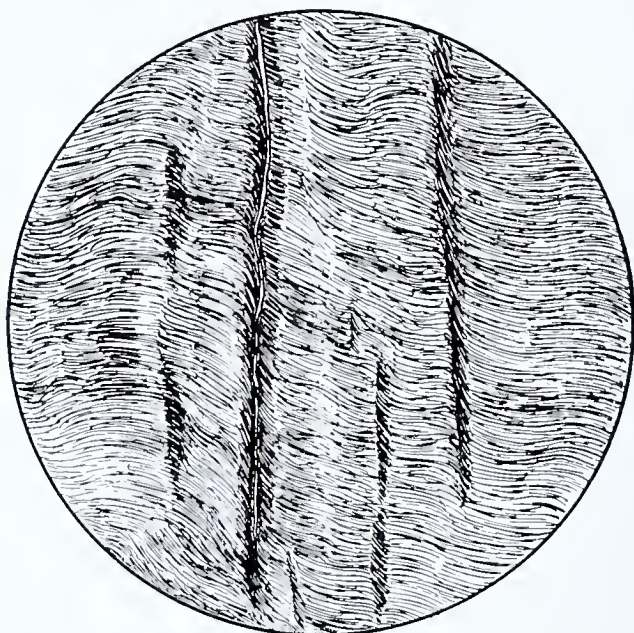


Fig. 13. False cleavage and incipient false cleavage in slate: the vertical open space is a false cleavage plane; true cleavage crosses from left to right. Enlarged 66 diameters.

Geological relations. There are several geological conditions under which false cleavage occurs. As already mentioned, it is most common near folded cleavage or near cleavage shear zones. Indeed cleavage shear zones, as here used, are really zones of closely-spaced false cleavage. False cleavage is also commonly seen near the crests of pitching folds; in these cases alone does the strike of the false cleavage planes meet the cleavage strike at a marked angle; examples are the false cleavage noted in the Custer and East End quarries at Slatington. A third mode of occurrence is where slaty and sandy beds alternate; this is probably the result of incomplete metamorphism in the more resistant sandstone and a resulting tendency for the sandstone bed to move as a unit, dragging the slaty cleavage with it and producing minor crinkling.

Regional occurrence. False cleavage was not observed to be conspicuous in the eastern part of the Lehigh-Northampton district; it is commonly seen farther west, however, especially in the quarries of Lehigh County. It is also common in the Peach Bottom quarries. For details, the reader is referred to the descriptions of these districts.

Origin. In the Alpine region of southern Germany false cleavage affects entire formations. Born¹ and others have described this feature, to which they have applied the term "wrinkled slate" ("Runzel-Schiefer"), as a further phase of metamorphism, following slaty cleav-

¹ Born, Axel, Ueber Druckschieferung im varistischen Gebirgskörper: Fortschritte der Geologie und Palaeont., Gebr. Borntraeger, Berlin, vol. VII, pp. 357-358, 1929.

age. This viewpoint is discussed in the section on the metamorphism of slate. While it is undoubtedly correct where large rock masses are affected, in its local occurrence it more properly represents the effect of renewed movement under conditions in which the slate responded physically rather than chemically,—that is, under which the mica flakes were strained and torn, rather than recrystallized.

The essential cause is a thrust to which the mica or chlorite crystals of the true cleavage cannot accommodate themselves by recrystallization. This probably results from insufficient time,—too rapid a rotational strain. Hence it is that most of the occurrences are at points of excessive shear,—such as between beds of slate and sandstone or at the crests or troughs of pitching folds where bed drags on the cleavage of adjacent bed.

Economic importance. In none of the Pennsylvania quarries is false cleavage sufficiently common to prohibit operations, though it contributes materially to the quantity of waste in several. Dale, however, mentions a quarry in Vermont¹ which was actually shut down on account of the wide-spread occurrence of false cleavage. At the time of quarrying, false cleavage does not always betray the extent to which it spoils the slate; this, of course, makes it doubly objectionable, since slate may be sold and used before its inferior quality can be detected.

In many of the Peach Bottom quarries the slate approaches a schist in structure, false cleavage in these cases being of general regional development. It shows plainly under the microscope yet does not visibly affect the use of the slate. However, the greater brittleness of Peach Bottom slate, of which quarrymen speak, in comparison with the slates of the Lehigh-Northampton district, is perhaps attributable to the prevalence of false cleavage.

CLEAVAGE SHEAR ZONES

Description. Cleavage shear ones are zones inclined to the true cleavage of the slate, along which the cleavage planes have been sharply distorted by warping or minute faulting. The feature passes gradationally into gently folded and finally into normal and undisturbed cleavage. The term may best be confined to megascopic structures; shear zones are the megascopic equivalents of false cleavage.

In a shear zone, the cleavage may be thrown into more or less gentle curves or the folds may actually be angular and step-like, and are then called “hogbacks.” Generally false cleavage is also developed, along planes parallel to the axes of the cleavage fold. An illustration is afforded by Figure 14. In the case pictured, small-scale thrust faulting appears to have taken place along the fracture cleavage planes on the lower limbs of a tiny anticline developed in the slaty cleavage. The traces of fracture cleavages are visible on the front and back of the block. There is also a tendency toward the thickening of slate between cleavage planes on the crest of the small anticline. In a word, the picture is one of typical thrust folding, except that slaty cleavage plays the role of bedding, while false cleavage simulates typical slaty cleavage in its relation to the fold.

¹ Dale, T. N., The slate belt of eastern New York and western Vermont: U. S. Geol. Survey 19th Ann. Rept., part III, p. 209, 1899.

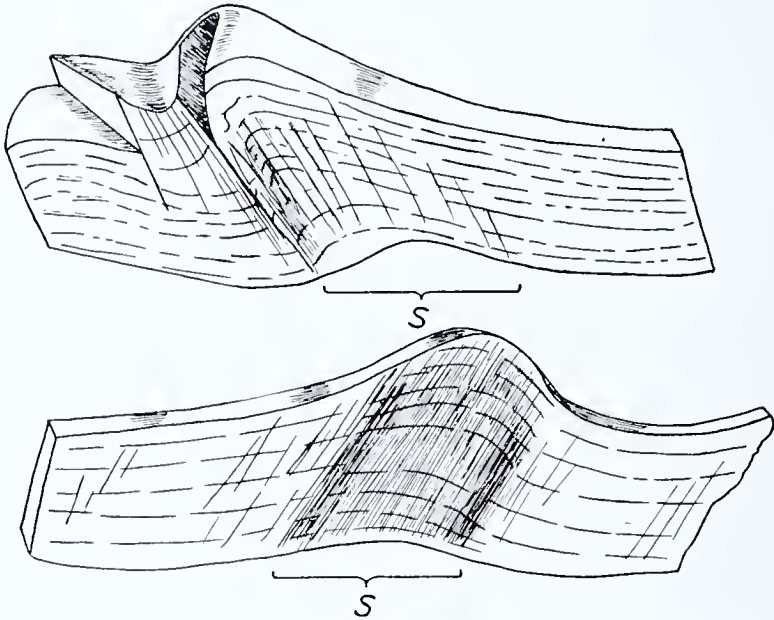


Fig. 14. Two views of a cleavage flake of slate showing a cleavage shear zone (S), and the associated false cleavage, $\times\frac{1}{2}$; the shear was more intense at one side than at the other. From Lehigh Valley Railroad cut, a mile south of Treichler's station, Slatington quadrangle.

Dale's "cleavage banding"¹ is evidently a more extreme development of the same feature. The writer has not observed cleavage banding in any of the Pennsylvania slates.

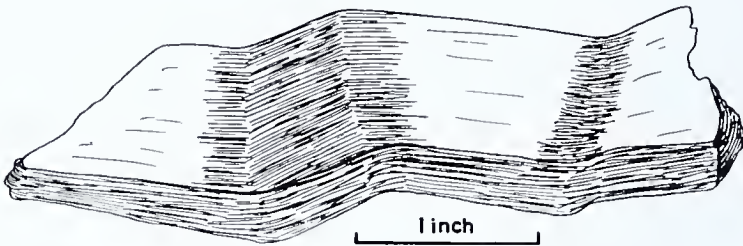


Fig. 15. Cleavage block of slate from Hess quarry near Lynuport, Lehigh-Northampton district, to illustrate a sharply angular cleavage shear zone; $\times\frac{3}{4}$.

Origin and economic importance. What has been said about false cleavage applies equally to cleavage shear zones. The close resemblance on a larger scale to the microscopic appearance of false cleavage, as well as their usual association, point toward a common origin for both. The economic significance of the two is also similar, except that cleavage shear zones are even more objectionable. If very well developed and

¹ Dale, T. N., The slate belt of eastern New York and western Vermont: U. S. Geol. Survey 19th Ann. Rept., part III, pp. 214-215, Plate XXX, 1899.

closely spaced the zones may yield a schist, with highly wrinkled cleavage surface, as indicated above; such a rock cannot possibly be worked for slate.

JOINTS

Description. Joints in slate, as in other kinds of rock, are fractures that cross the body of the rock for megascopic distances, and along which there has been little or no movement. In slate they are generally smooth planes, frequently warped. Merrill and Mathews¹ figure a curved joint face in a Maryland quarry. Dale describes a conical structure, 20 feet high and 15 feet in diameter at the base, produced by curved jointing in a slate quarry near Delta, Pa.² He also cites a case of plicated jointing in a Vermont quarry.³ Such curved joints are known in several slate operations in Pennsylvania, notably in the Lehigh-Northampton district (see Plate 9). The curvatures appear to be of two different types, illustrated by the two figures in the plate referred to and each clearly related to other geologic features. In one of these types the troughs and depressions are relatively regular and are parallel to and coextensive with the traces of beds on the joint face; the curves seem to be due to the angle of rupture in the material making up the different beds. In the second case there is developed a surface with "wrinkles" which suggest irregular drag along the joint plane; the major joint is frequently intersected by minor fractures, at which it is offset *en echelon*. These lesser fractures, however, appear as breaks limited at their ends by their intersection with the master joint, and there is thus no definite evidence that they are of later origin.

As every geologist will realize, many joints bear fillings. In the slate, these are most commonly calcite or aragonite, or more rarely quartz. Three miles west of Lynnport, in Lehigh County, two small long abandoned quarries show ribboned, soft slate; this is cut by closely-spaced "gash" joints, the total length of which does not exceed six inches; the openings are filled with fibrous calcium carbonate. Not uncommonly joints bear tiny crystals of pyrite, usually set in small regularly lenticular depressions suggestive of geodes but clearly of different origin. Dale⁴ also mentions cases where dikes occupy joint crevices.

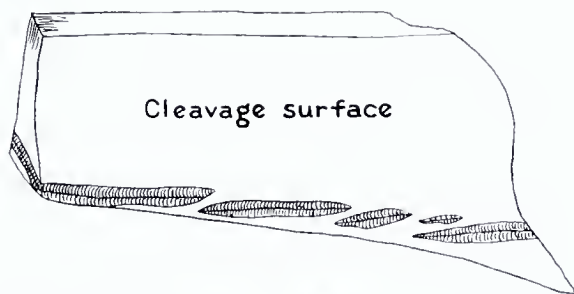


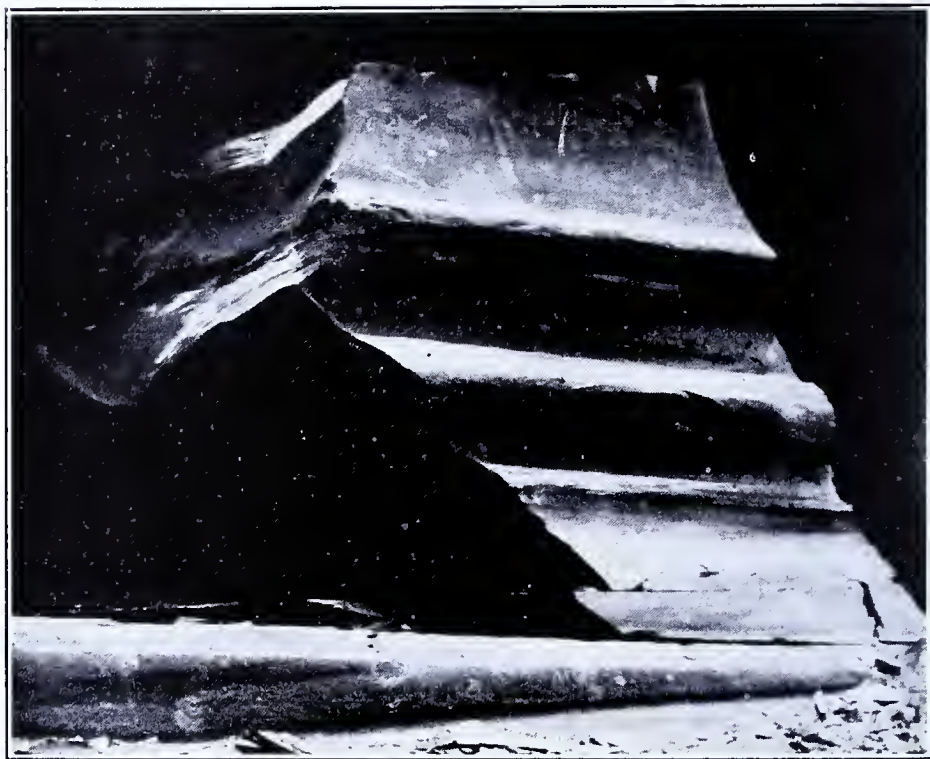
Fig. 16. Sketch of aragonite-filled gash joints in slate from quarry half a mile north of Slateville, Hamburg quadrangle; $\times 1$

¹ Merrill, G. P., and Mathews, E. B., *The building and decorative stones of Maryland*: Md. Geol. Survey, vol. II, part II, plate XXXII, fig. 1, 1895.

² Dale, T. N., *Slate in the United States*: U. S. Geol. Survey Bull. 586, p. 42, 1914.

³ Op. cit., p. 42-43, 1914.

⁴ Dale, T. N., op. cit., p. 42, 1914.

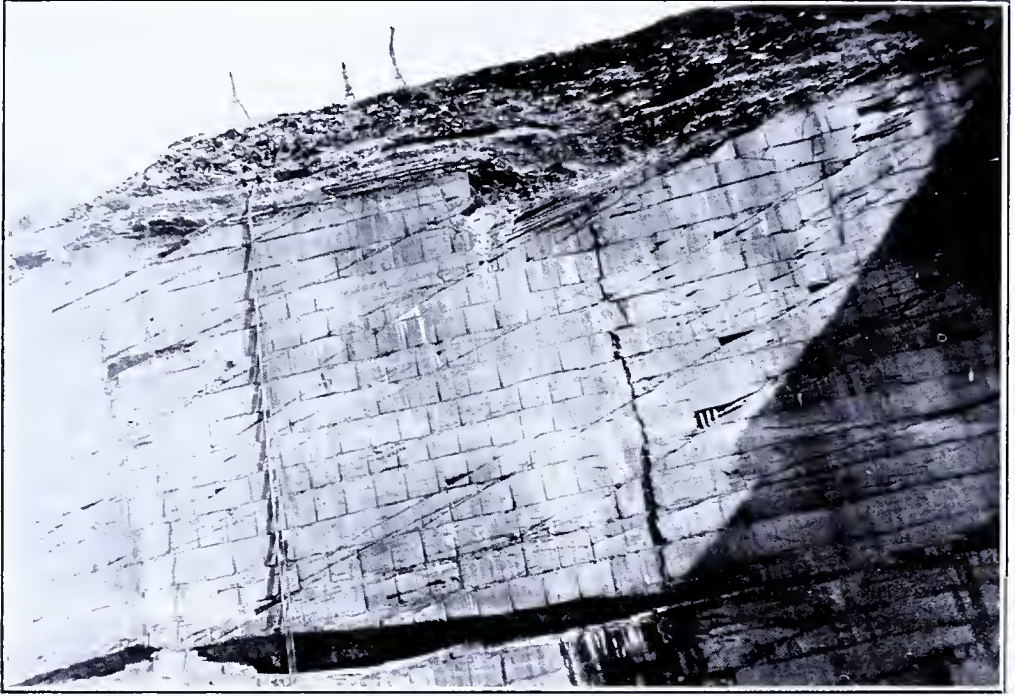


A. Joint surface, curved where it crosses beds of varying composition; height of exposed surface, 2 feet. Albion quarry.



B. Joint surface, "wrinkled" and cut by minor joints; length of exposed surface, 6 feet. Columbia Bangor quarry.

PLATE 10.



A. Regular jointing in upper part of southeast wall, Albion quarry. Joints run obliquely downward to left; the more nearly horizontal lines are channel machine cuts.



B. Part of northeast wall of Consolidated No. 1-Star quarry, showing numerous joints striking parallel, N.30-35° E.

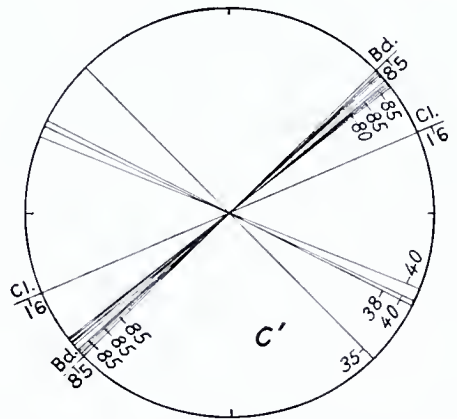
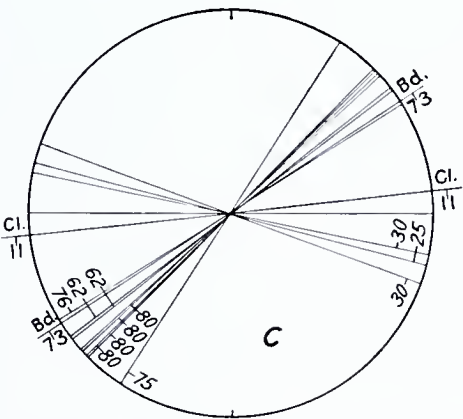
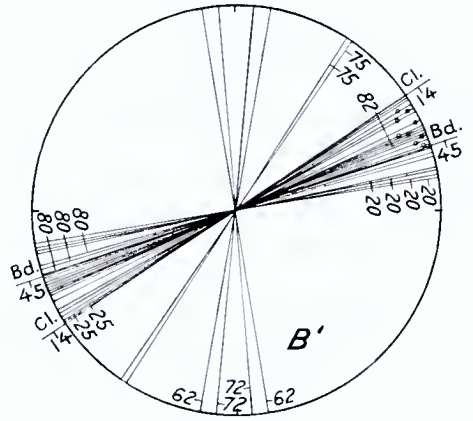
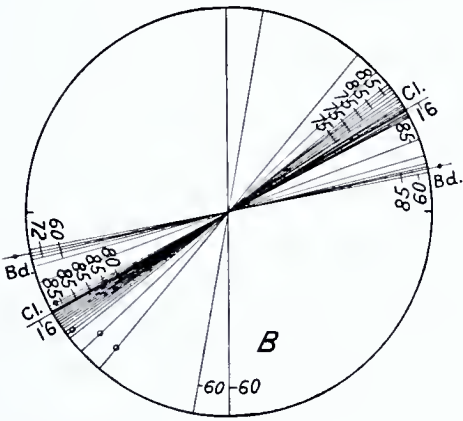
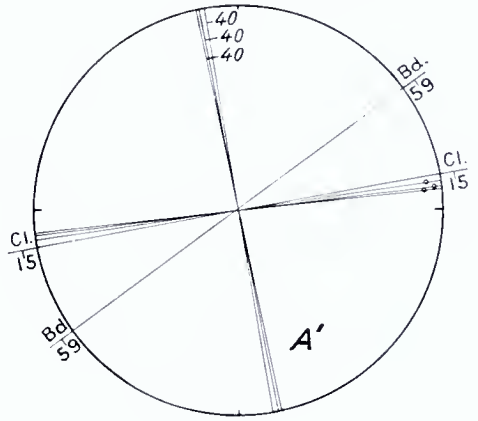
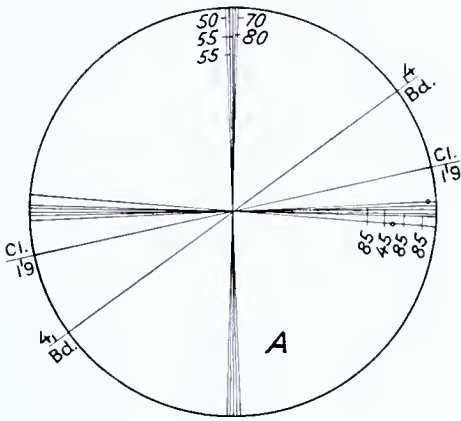


A. Zone of movement along cleavage plane, lowest level, Belfast quarry; two quartz lenses are seen, one being marked by the hammer head; direction of cleavage indicated by arrow.



B. Striae or slickensides on a calcite-coated bedding or joint plane, Slatington, Pa.; shows the effect of movement.

PLATE 12.



Joint-strike diagrams of six quarries in Lehigh-Northampton district. Quarries similarly lettered are close together; note similarity in joint patterns.

A. (Bangor Central) and A' (North Bangor No. 3) at Bangor.

B. (Chapman Standard) and **B'** (Chapman, east opening) at Chapman; **C** (Parsons) and **C'** (Albion Vein) at Pen Argyl.

(4) Near faults, especially those of the bedding-slip variety, the jointing is likely to be closely spaced and to resemble short gashes, the planes of which make acute angles with the fault plane. In such places the slate is likely to be badly broken, with deformed cleavage.

In the Peach Bottom district an unusual type of jointing is commonly observed. This consists of a sheeted zone representing several closely spaced joints, dipping in various directions but always only slightly inclined to the horizontal,—seldom with an angle of more than 20° . Thus at the Humphreys quarry, near the West Bangor store, three such zones are seen, striking approximately due east and dipping 15° N; in the northeast corner they are at depths of 25, 40, and 75 feet below the surface. Steeply inclined single joints generally end against these zones. As a rule the slate shows considerable oxidation with rusting at these horizontal joints. This feature has also been described by Dale.¹

Joint systems. Sets of joints having approximately the same dip and strike are referred to as “systems.” The only well-marked system, to the writer’s mind, is composed of the joints already mentioned, which are parallel in strike to the bedding.

Age of joints. Most of the joints seem to be distinctly later than the cleavage. They cut the cleavage at all angles, both in thin section and hand specimen. A thin section of a calcite-filled joint shows the mesh-work of the mica pulled apart along the joint with irregular curvature of the grains and with some calcite infiltrating the rock between the mica flakes. It is evident, furthermore, that any recrystallization of the original shale to give slaty cleavage would have “healed” pre-existing joints.

From the close relationship between joints and faults, especially in the case of bedding-slip faults, it is clear that many joints are contemporaneous with faulting; they probably represent minor adjustments that accompanied the true faulting.

Economic bearing. The importance of joints to the quarryman is threefold. First, if advantageously spaced and possessing a favorable attitude, they are beneficial. Advantageous spacing is at intervals of not less than three feet. Favorable attitudes would be given by a strike approximately at right angles to other joint systems and, in the case of one set, normal to the beds or to other structural planes, such as cleavage. Joints which meet at acute angles, on the contrary, yield too much waste in the triangular slivers of slate between them; this is also true if joints bevel the cleavage at a low angle. Joints too closely spaced are clearly objectionable because the slate between them contributes greatly to the total waste.

A second sense in which joints are of economic importance is that they are generally more open than the cleavage and are thus the chief channels along which water enters the quarry; even if they are calcite-filled, solution cavities are soon formed. A heavily jointed quarry wall is therefore likely to lead to drainage difficulties.

A third significant bearing of jointing on quarry operations is in weathering which frequently follows the joints. This is especially well marked in the Peach Bottom district, where it has been described

¹ Op. cit., p. 113, 1914.

by Dale¹; thin sections examined by the writer show considerable limonitization of the slate bordering the joints. Megascopically the slate develops a rusty hue, as opposed to the very dark gray of the fresh slate. Similar but far less conspicuous changes take place along joints in the other Pennsylvania slates.

MINOR STRUCTURES

"Catspaws" or "blisters." There are features showing on the cleavage faces of slate. They resemble very low domes with heights of less than two inches and diameters not exceeding two feet, projecting above the normally flat cleavage by a series of steps concentric to their peaks. They resemble the percussion marks made in flint when the latter is chipped,—the reverse of conchoidal fracture. They may be coated with iron-stained calcium carbonate.

By analogy with the chattermarks in flint just mentioned, these features suggest the effect of sudden pressure. The cause, however, is uncertain: they are certainly not due to blasting, as this is carried on in all quarries, whereas "catspaws" are of limited distribution.

"Watersplits." These are crevices similar to joints, but less regular and with almost no gap; they form low angles with the horizontal and generally also with the cleavage. They appear in quarries after a smooth and extensive cleavage surface has been laid bare, especially when one or two of the quarry sides are freed by channel cuts. By the quarrymen they are attributed to the action of the water "working its way through" the slate. It is highly improbable, however, that water itself can form openings in slate, and the expansive force of ice cannot be appealed to, as the crevices form in warm as well as cold weather; moreover they are evidently newly-formed openings, which must be formed before they can conduct the water to form ice.

Most probably the correct explanation is the relief of pressure with the reduction of superincumbent load. When a quarry has reached some depth, the overburden is greatly reduced in the opening, but still exists on the sides. There is thus a relief of pressure within the confines of the quarry, which permits the slate in the quarry floor to bulge upward slightly for one or more of the following three reasons:

1. The buried slate is normally under great pressure, due to the rock above; when this is removed the slate "springs" upward.
2. The walls of the quarry, no longer held apart, now that the slate has been removed, creep inward and buckle up the slate in the quarry floor.
3. Pressure exerted near one end of the top of a pack of cards tends to lift and separate the cards at the opposite end of the pack; in a similar way, the rock presses downward and separates the slate along the horizontal planes; this can, of course, only be effective when one side of the slate is free and the opposite side is not free.

Probably the sudden appearance of "watersplits" is best accounted for by the second and third explanations. They thus resemble "rock bursts" or "spalls" in mines.² Similar movements in rock quarries have been noted elsewhere. Thus, Buckley and Buehler³ describe the

¹ Op. cit., p. 114, 1914.

² See for example, Crane, W. R., Iron ore (hematite) mining practice in the Birmingham district, Ala.: U. S. Bur. Mines Bull. 239, p. 80, fig. 61, 1926.

³ Buckley, E. R., and Buehler, H. A., The quarrying industry in Missouri: Mo. Bur. of Geol. and Mines Report, vol. II, 2d ser., p. 127, 1904.

gradual closing of channel cuts in limestone quarries. More recently Bain has measured similar creep in the floors of marble quarries.¹

The low angle at which "watersplits" cut the bedding makes them especially productive of waste in quarrying. For this reason there has been much discussion of ways to prevent their formation. Among quarrymen the impression is general that "watersplits" may be prevented by covering the slate with hay, sod, water, or other matter to exclude free air circulation. In the opinion of the writer this is fallacious. The best protection is probably to separate the floor from all of the quarry walls by deep channeller cuts; if the causes of "watersplits" are as inferred in the preceding discussion, the purpose of such measures should be obvious.

"Slaunts." In the Peach Bottom district the quarry walls not uncommonly show joint-like fissures, inclined at gentle angles to the cleavage, locally containing a black, clayey substance, probably gouge produced by movement, which Dale has found to consist of pyrite, carbonaceous matter, quartz, chlorite, and muscovite.²

There is much uncertainty as to the proper interpretation of these features. The "slaunts" observed by the writer all have very steep dips and in some cases, as in the McLaughlin quarry, half a mile east of the West Bangor store, York County, the marked parallelism of the "slaunts" and their structural relations leave a strong impression that these are merely ill-defined bedding planes. This impression is furthered by the fact that all "slaunts" have a strike virtually parallel to the cleavage and are thus suggestive of isoclinally folded beds. Locally they are continuous with curved planes of parting, which may represent beds on the crest of folds, but may also merely be curved joint planes; illustrations of this feature are seen on the southwest wall of the R. L. Jones quarry and on the northeast wall of the Faulk Jones quarry, both of which are short distances east of the McLaughlin opening. Like occasional bedding planes in the Lehigh-Northampton district, some "slaunts" are lined with calcite which may show slickensiding.

For the present the writer accepts tentatively the hypothesis that "slaunts" are due to parting along bedding planes. Within the Peach Bottom slate district this hypothesis is all that affords any hope of interpreting the bedding structure within the slate itself.

Like "watersplits," "slaunts" increase quarry waste because of their low angle of intersection with the cleavage.

MUTUAL RELATIONS OF STRUCTURAL FEATURES

General considerations. In the last analysis, the successful operation of a quarry depends largely upon the fortuitous relations between bedding, cleavage, grain, jointing, and (to a less extent) minor structural features. From what has been said in respect to each of these features, the thoughtful reader will recognize the importance of these mutual relations. Several of the more conspicuous instances may, however, be cited here.

¹ Bain, G. W., Spontaneous rock expansion: Jour. Geol., vol. 39, pp. 715-735, 1931.

² Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, p. 114, 1914.

Bedding—cleavage relation. Quarrymen speak of slate as having “length.” This is the length from end to end, generally measured parallel with the grain, of a cleavage flake of slate within one bed. Thus in Figure 10, the length of slate available between the two black beds would be measured along the line of intersection between the cleavage and the grain plane.

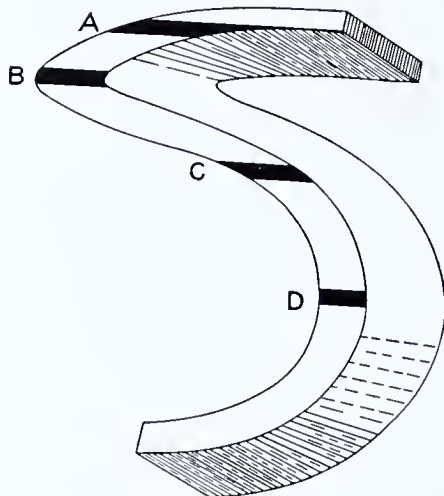


Fig. 18. Stereogram of a single slate bed, showing cleavage-bedding relations. As the cleavage bisects the opening angles of the folds, a longer piece of slate is obtainable along the cleavage at A, even though the bed is here actually thinner, than at B, C, or D.

A reference to Figure 18 clearly illustrates that the length thus varies inversely with the angle between cleavage and bedding, and hence that, other things being equal, a quarry opened in a “tight” fold like the upper part of Figure 18 (A, B) is more profitable than one in an open fold, such as that at C and D. This fact presents a distinct advantage for the Bangor quarries in the Lehigh-Northampton district, where the folds are generally tight. Sometimes, however, if the beds are severely thinned on the limbs by intense compression, such an advantage is nullified.

In the middle and lower members of the Martinsburg formation, in the region to the southwest of Slatington, the individual slaty beds between sandy layers are frequently less than an inch thick. Under existing conditions the quarrying of cleavage blocks would yield slate that was either not workable at all or was crossed by ribbons. Locally, however, the bedding meets the cleavage at a very low angle and hence long slabs of slate may be obtained, as in quarries at Roekdale and Scheidy, that show no ribbons. Unfortunately, how-

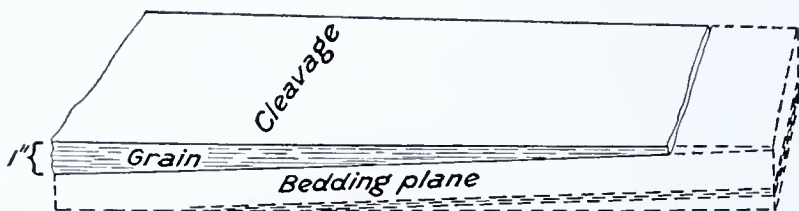


Fig. 19. Sketch of “unribboned” roofing slate made from thin-bedded “hard” slate at Scheidy, Lehigh County. The dashed lines show the shape of the original block before splitting one face parallel to bedding.

ever, these slabs tend to split along individual bedding planes as well as on the cleavage, and thus converge in one direction.

Bedding—grain relation. As the slate is generally broken parallel to the grain, the removal of rectangular pieces—a condition favoring the reduction of trimming losses—is dependent in part on there being a right angle between grain plane and bedding strike. This is illustrated in Figure 20. In the figure on the left, rectangular blocks can

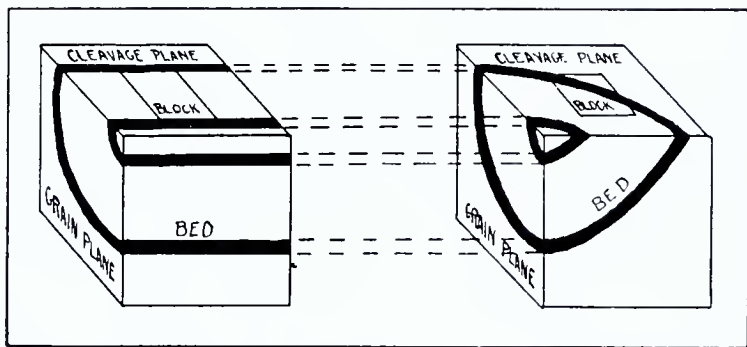


Fig. 20. Diagram showing effect of relation between grain and bedding on quarrying: relations are favorable in the figure to the left, unfavorable in that to the right.

be broken out between the two ribbons because the grain plane is parallel to the dip of the beds. In the figure on the right, it is impossible to break out a block of similar area with its sides parallel to the grain, without taking also some of the undesirable ribbon.

Bedding—joint relation. It should be clear that the ideal relation between jointing and bedding strikes is an intersection of 90° . This reduces the waste occasioned by trimming the slate pieces to bring their edges parallel to the bedding,—a procedure sometimes necessitated when individual layers break loose along the bedding planes.

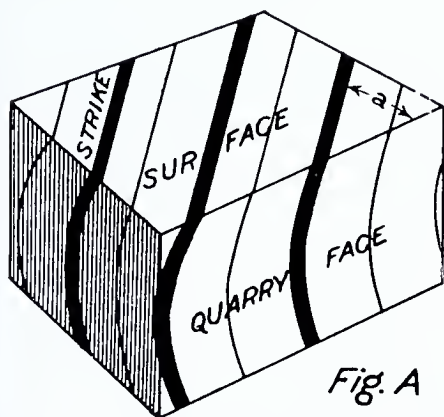


Fig. A

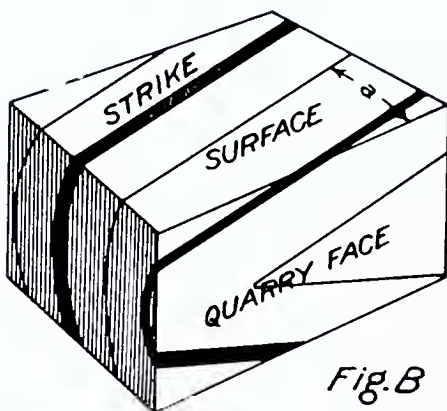


Fig. B

Fig. 21. Diagram to show how differences in the angle "a" between the quarry wall and the strike of bedding affect the bedding patterns on the quarry wall. It also indicates that more unribbed slate is produced when the angle "a" between jointing (represented by the surface marked "Quarry Face") and bedding strike is small than when it is large.

ORIGIN OF SLATE BY METAMORPHISM

With a few economically negligible exceptions¹, slate is a rock which was once sedimentary,—that is, it was originally deposited as a sediment by wind or water—generally, water—on land or in lake or sea—most commonly in a body of water. Subsequent to this deposition it has been altered by severe compression. It is this compression that has given to the rock its distinctive characteristics.

Original constitution and shale formation. The usual first stage in the development of slate is the deposition of clayey mud in marine or fresh-water seas. This mud consists of particles of clay (roughly, the mineral kaolin²) with several other constituents, such as quartz grains (sand), mica flakes, and carbonaceous particles, and some colloidal semi-liquids like iron oxide and silica. In addition the mud bears intergranular moisture and the particles mentioned may have adsorbed films of various salts, especially of potassium, sodium, magnesium, and calcium carbonate. This matter, taken together, may loosely be termed mud or fine silt.

As successive layers of such constituents accumulate to greater and greater mass or other kinds of sediment are piled up on the earlier layers, more and more downward pressure is exerted. This induces compaction. The first effect is to crowd particle against particle and drive off much of the liquid that was hitherto adsorbed or held in the pores. As particles abut against their neighbors a reorientation by slow rotation takes place and the particles come to lie with their longer dimensions parallel to the sea bottom and hence also to the layer of which they are a part. At this stage the rock is compact and has lost most of its moisture and tends now to break parallel to the bedding or layers; it has a clayey odor and is called shale. Mineralogically it consists of much the same substances as the original mud, except that, according to certain geologists, some secondary white mica is formed, perhaps through the reaction of the aluminum silicate of the clay minerals and the potassium carbonate of the absorbed water.³

Change from shale to slate. If shale is to become slate a second step must follow. This is distinctly related to the larger geologic features of the region. For some cause, not clearly understood, the rocks in the outer part of the earth are periodically subjected to severe compression from the sides; this has been assigned to a shrinkage of the earth's "core" with a consequent contraction of the outer layers, but that explanation is not uniformly accepted. In any case, the compression mentioned forces the rock layers to shorten and wrinkles them into folds. In the more surficial layers of the earth such folds simply increase in amplitude as compression becomes more intense, or they are broken by faults.

In the deeper layers, however, the rocks tend to adjust themselves internally. Such internal adjustment in rocks that were once shales usually results in the development of new minerals and the more or less complete obliteration of the structures which characterized the

¹ Eekel, E. C., On a California roofing slate of igneous origin: Jour. Geol., vol. XII, pp. 15-24, 1904.

² Accurately at least five important clay-like minerals having crystalline characters, and probably others that are colloids. See Ross, C. S., and Shannon, E. V., Minerals of the bentonite and related clays and their physical properties: Am. Ceramic Soc. Journal, vol. 9, p. 87, 1926. Ross, C. S., and Kerr, P. F., The kaolin minerals: U. S. Geol. Survey Prof. Paper 165-E, 1931.

³ Hutchings, W. M., The origin of some slates: Geol. Mag., vol. VIII, p. 168, 1890.

rocks previously. This formation of new minerals is commonly called "dynamic metamorphism," because it can be attributed to the active force of compression, or "regional metamorphism," because it is generally observed to extend over larger regions of the earth's surface. Pressure, especially from the sides, is the essential causal agent, but heat may also aid. The more theoretical consideration of the changes comprised under dynamic metamorphism cannot be taken up here¹ but will be briefly dealt with in a later section.

Dynamic metamorphism commonly has two striking effects upon shale. Megascopically it gives to the altered rock a very pronounced tendency to part along sub-parallel planes, which is called cleavage and which has already been described under that title. The planes of parting are parallel or sub-parallel; the more strictly parallel and the more closely spaced the planes, the more perfect is the cleavage and the more nearly may the resulting rock be regarded as true slate. It may be added that the cleavage planes have two other characteristic properties: they are regionally uniform,—that is, they have approximately parallel positions throughout large areas, and they cut across the bedding with little or no regard to preexisting bedding planes.

The second striking effect only becomes apparent upon microscopic examination. It is then seen that, in place of the poorly oriented particles of clay which made up the greater part of the shale before the metamorphic process, the newly-formed rock is composed largely of flat particles of mica, with or without chlorite and other minerals not previously developed. Most of these new minerals possess conspicuous elongation in one or two directions and have the directions uniformly oriented in the rock mass. The effect of this uniform parallelism in the long axes or flat surfaces of fibrous and platy crystals is clearly what conditions the megascopically observed slaty cleavage.

It is obvious that the perfection of slaty cleavage will depend jointly upon the completeness with which the entire rock is recrystallized into the minerals in question; upon the perfection of parallelism in the greater dimensions of these mineral particles; and upon the extent to which the new minerals developed are of the platy or fibrous types and thus capable of contributing a definite cleavage to the rock mass.

In a general way, subject to certain theoretical qualifications, it may also be noted that the longer axes of the newly developed minerals are arranged at right angles to the stress which brought about the cleavage. The cleavage planes, since they are the planes of these longer dimensions of the particles, may thus be used to determine the direction of maximum compression to which the rock has been subjected. It is characteristic of regional metamorphism that the maximum stress direction is uniform over large areas; hence cleavage also (megascopic) and mineral elongation (microscopic) will be uniform over large areas.

Causes of cleavage and mode of recrystallization. The student of metamorphic geology will find the preceding sections a mere restatement of the most elementary facts. They have been written for the slate producer or consumer or the production engineer, rather than for the tectonic geologist. It does not seem necessary, in view of the purpose of this bulletin, to discuss in full the theoretical bearing of

¹ See especially Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. XLVII, 1904; Leith, C. K., and Mead, W. J., Metamorphic geology, Henry Holt and Co., New York, 1915; Grubenmann, U., and Niggli, P., Die Gesteinsmetamorphose, Gebr. Borntraeger, Berlin, 1924.

stress and recrystallization upon the development of slate through metamorphism. The writer permits himself, however, the following remarks upon the more intricate theoretical aspects of these problems. Structural features resulting from metamorphism are separately described under the title "Secondary Structural Features" (see page 21).

There has been much discussion as to the causes of slaty cleavage. That true cleavage is due to parallelism in the longer dimensions of the chief mineral constituents seems well established. But several questions may be raised:

1. What is the nature and direction of the deforming pressure and how is it transmitted?
2. How does the rock respond?
3. What is the role of the overburden?
4. How does time affect the deformation?
5. What is the greater limit of deformation in forming slate,—at what point under increase of metamorphism does slate pass into schist?

1.—In considering the pressure that develops true slate, it is necessary to study the behavior of the rock as a whole, rather than the unit crystals. The latter method has yielded excellent results in the hands of Sander¹ but is unsatisfactory in dealing with most commercial slate for the following reasons: (1) even if the rock be thought of as behaving much like a liquid, in that its ease of recrystallization yields a texture which approximates that of plastic flow, the variability in the resistance to solution and distortion by the crystal units makes physical analysis in minute quantities unimportant in reference to physical behavior of the rock as a whole; (2) though heterogeneous in detail, the formation is homogeneous as a whole, and the unvarying strike and dip of slaty cleavage through large volumes invalidates consideration of forces that are only operative through small sections of the mass.

In general, the effective pressure that develops cleavage is clearly horizontal (or, more properly, tangential). It is well recognized that a certain minimum pressure caused by overburden is requisite for the development of slaty cleavage, but that this does not enter as an effective component is obvious from an analysis with assumed increase in lateral compression. The same consideration is apparent from the areal relations of nearly horizontal cleavage in slate (as, for example, at Bangor, Pennsylvania); such horizontal cleavage is clearly the effect of thrusting or overfolding and consequent tilting; it represents a flattening of the ellipsoid of strain, as pointed out in analogous fault instances.²

Whether or not the strain is rotational or irrotational is again not recognizable from the results; the effect of both types of deformation will be the same. However, the presumption is that at least the later strain is rotational in all those cases where the cleavage occurs in folded beds and stands inclined to the vertical, as the very attitude of the fold axes indicates shortening, and shortening in a vertical direction through folding is not acceptable for tectonic reasons.

¹ Sander, Bruno, *Gefuegekunde der Gesteine*, Julius Springer, Wien, 1930.

² Chamberlin, R. T., and Miller, J. G., Low-angle faulting: *Jour. Geol.*, vol. 26, pp. 1-44, 1918.

We may, therefore, regard the forces that initiate slaty cleavage as being essentially tangential, leaving out of account for the moment the angle between the cleavage planes and the planes of shear in the strain ellipsoid thus developed.

When the strain ellipse is resolved, it is seen that the component of maximum stress is at right angles to the maximum elongation of the ellipse at any single moment. This is the case whether the interpretations of Becker or of Leith, discussed below, are accepted. The major force transmitted passes through the rock mass in virtually parallel directions and essentially uniformly; in the latter respect it resembles hydraulic pressure, a concept supported by the regional uniformity of cleavage-plane position, as opposed to the stress irregularity in the earlier stages of folding that is indicated by irregular pitches in the axial lines of the folds. Particle impinges upon particle, and although initial compactness was assured by the pre-cleavage folding, differential pressure through the rock mass as a whole remains assured by continued tangential contraction and further adjustment becomes necessary. A general homogeneity of the rock material is essential to this uniform pressure, otherwise a flowage of this less resistant or less soluble material around the more resistant particles would result.

2.—The question of the manner of response of the rock is obviously identical with that of the origin of slaty cleavage. Sorby¹ regarded slaty cleavage as essentially a depositional feature, but even much earlier its secondary nature was recognized.² Since the time of Sorby the cause of cleavage has received critical study by Van Hise, Becker, Leith, Grubenmann, Schmidt, and many others.

Two fundamentally different viewpoints may be recognized. The first of these attributes slaty cleavage to essentially physical, supra-molecular or at the least molecular adjustments, without important chemical change. The second interpretation assigns slaty cleavage to chemical changes,—primarily solution and recrystallization. Nearly every geologist has accepted both types of processes, but has either stressed one or the other as the more important. Many have appealed to "flow", meaning by this term a special kind of adjustment very different from the irregular behavior of molecules in a non-rigid mass.

Among those who assign cleavage chiefly to physical adjustments, Leith and Becker may be mentioned. Becker³ assigns cleavage to "flow" and cleavage planes are called homologues of shear planes. Despite the great contribution made by Becker's analysis, serious objections must be raised against applying this viewpoint to slaty cleavage. There is no evidence of frictionless movement within the rock mass in the growth of slate. Indeed, true flowage cannot take place after the definitive relative position and thickness of the parts of folds are attained, whereas almost all of the process of cleavage formation must follow that attainment,—otherwise the cleavage itself would be deformed. Nor is there any tendency toward rupture through scission. Slaty cleavage is thus neither due to shear nor to true flow. This fault in an otherwise very stimulating and careful study is recognized by

¹ Sorby, H. C., On the structure and origin of non-calcareous stratified rocks: *Quart. Jour. Geol. Soc. London*, vol. 36, p. 70, 1880.

² Phillips, John, *The cabinet cyclopaedia*,—*Natural History*, vol. I, London, 1837, pp. 125-126.

³ Finite homogeneous strain, flow, and rupture of rocks: *Geol. Soc. Am. Bull.*, vol. IV, pp. 13-90, 1893; Schistosity and cleavage: *Jour. Geol.*, vol. IV, pp. 429-448, 1896; Schistosity and cleavage: *U. S. Geol. Survey Bull.* 241, 1904.

Sander.¹ Becker's shear, seission, or cleavage planes are, in short, comparable with the "fracture cleavage" planes of Leith, and even occupy identical positions in the strain ellipsoid.

Like Becker, Leith² speaks of rock "flowage", by which is meant any type of internal adjustment, some of it chemical; this permits too wide a construction of the term "flowage". Of Leith's four ways in which cleavage ("flow cleavage") is brought about³ two only are of importance in commercial slates, the other two operating chiefly in rocks of heterogeneous mineral composition or in such as are highly calcareous.

Gliding, though operative, especially along the mineral cleavage planes, is not conspicuous in most slates. If it were an essential feature in the development of slaty cleavage, the resulting "en echelon" arrangement of the particles should be common; instead it is very rarely observed, and even then is almost wholly confined to large calcite individuals or to feldspars, both of which are constituents of very minor importance in most well-cleaving slates. It is, however, well displayed in schists and in other highly deformed rocks.⁴

Granulation is an aid to recrystallization—a "chemical" process—and to "rotation"—a physical one—for it favors solution and, when followed by compaction, it may yield the space into which some particles can rotate. In slates it is especially important to the extent to which quartz grains are affected.⁵ The chief constituents of slates, however, are essentially porphyroblastic; far from suffering comminution, they have actually been enlarged in size.

Rotation of individual grains, so as to bring the larger dimensions into positions essentially parallel with each other and with the cleavage, is probably of considerable importance. In slates and schists it has been described by Grubenmann and Niggli, by Schmidt, Sander, and others,⁶ especially in the case of porphyroblasts which suffered rotation during their formation. Very careful measurements have shown that quartz in schistose rocks has a definite crystal elongation with respect to slaty cleavage.⁷ Though not quantitatively studied, microscopic examination of Pennsylvania slates by the writer points partly to recrystallization, especially at the *ends* of the longer axes of the grains, but also in part to rotation, as the boundaries of the original grains are visible in many cases and the quartz shows undulatory extinction developed by strain. Naturally such rotation is seen only in grains or crystals which (1) are composed of a mineral sufficiently rigid to resist bending, (2) consist of a mineral lacking cleavage planes along which gliding may take place, (3) possess a distinctly longer dimension, so as to favor development of unequal stress, and (4) were present before the origin of the slaty cleavage. Even minerals which might, near the surface, be regarded as highly resistant to bending and gliding may at depth yield in these manners, rather than by rotation.⁸ In slates, however, where the mica flakes form the dominant mesostasis between such more refractory grains, the latter are able to adjust themselves by displacing the more soluble and less rigid mica.

¹ Gefuegekunde der Gesteine, Julius Springer, Wien, 1950, p. 99.

² Leith, C. K., Rock cleavage: U. S. Geol. Survey Bull. 239, pp. 65-66, 1905.

³ Op. cit., pp. 71-76, 1905.

⁴ See, for example, Leith, C. K., op. cit., Plate XII, A, 1905.

⁵ Sander, Bruno, op. cit., p. 175.

⁶ For examples see Grubenmann, U., and Niggli, Paul, Die Gesteinsmetamorphose, Part I, Gebr. Borntraeger, Berlin, 1924, p. 469; Sander, Bruno, op. cit., p. 224.

⁷ Schmidt, W., Statistische methode beim Gefuegestudium kristalliner Schiefer; Wiener Akad. der Wissensch. Sitzungs-Bericht, vol. 126, 1917.

⁸ Sander, Bruno, op. cit., Fig. 66.

As to the opposing theories of Becker and Leith with respect to orientation of slaty cleavage, it is readily seen that they approach each other; this is especially true, as pointed out by Sander,¹ if internal rigidity and friction under pre-cleavage conditions are lacking or nearly so, in which case the angle between the maximum stress direction and the planes of shear approaches 90° ,—that is, it approaches the relation inferred by Leith. Bucher's development of the angle of shear and maximum stress leads to the same conclusion² if shale in its pre-slate condition approximates a plastic rock, as is most likely the case.

To be entirely satisfactory, any explanation of cleavage must include extensive recrystallization. The general lack of deformation in the predominant constituents of the rock, especially mica and chlorite, seems to argue against rotation, gliding, and granulation as the principal means of adjustment. The essential change from shale to slate is in the growth of the secondary mica,—a chemical process. This fact, though perhaps not generally given the proper emphasis, was certainly well recognized by Van Hise and Leith;³ lately it has been amplified and restated by Berg and by Grubenmann and Niggli.⁴

It has generally been inferred from petrographic relations and has more recently been demonstrated by experimental methods⁵ that enough potassa can be held through "sorption" by clayey compounds to yield the 3 : 1 molar ratio with hydrous aluminum silicate necessary for the making of potash mica; such "sorption" is greatest if the potash is in the form of the carbonate, and probably becomes a chemical reaction, in place of ad- or absorption when pressures are sufficiently raised. Thus, a clayey mud laid down in the sea may already have approximately the constituents required to give mica.

Let the shale be assumed to consist initially of irregularly shaped particles of "clay" arranged with longer dimensions at random, as well as rarer grains of quartz and other minerals. If force is exerted on the irregularly shaped clayey particles, by pressure transmitted through adjacent grains, the stressed grains, at the contact point, will become slightly soluble (Rieke's principle⁶) in aqueous solution of potassium carbonate. In such cases the process of solution is highly selective especially in so heterogeneous a rock as clay,—both as to mineral species (mica perhaps being more soluble than quartz), and as to individual crystals of the same species. The product is a semi-liquid or a liquid, which, if the rock continues under direct stress, tends slowly to move into a region of reduced compression,—namely, the space where grains are not actually in close contact; most generally this is at the frayed-out ends of the crystals. Here potassa, alumina, and silica ions, dissociated from their original compounds through solution, may recombine chemically so as to yield the complex molecules of sericite and related micas. If Fe_2O_3 and bivalent metals of the alkaline earth-group are present, there results a growth of chlorite in place of sericite. Constant elongation in the direction of least stress and simultaneous reduction by solution in the opposite direction finally produce particles which abut

¹ Op. cit., p. 99.

² Bucher, W. H., The mechanical interpretation of joints: Jour. Geol., vol. XXIX, pp. 14-16, 1921.

³ Van Hise, C. R., Treatise on metamorphism: U. S. Geol. Survey Mon. XLVII, p. 778, 1904; Leith, C. K., op. cit., pp. 67-70, 1905.

⁴ Op. cit., pp. 463-464.

⁵ Noll, W., Die Sorption des Kaliums in tonigen Sedimenten und ihre Bedeutung für die Bildung des Kaliglimmers bei der Metamorphose: Chemie der Erde, 6 (1), pp. 1-50, 1930.

⁶ Rieke, E., Zur Erniedrigung des Schmelzpunktes durch einseitigen Druck oder Zug: Zentralbl. f. Min., p. 97, 1912.

against each other at their ends; yet even thus growth may be continued by a closer dovetailing of such ends until the texture is finely meshed and interwoven so that no unoccupied space exists in the mass. During this process, preexisting and commonly impure crystals, not accordantly oriented, are being selectively eliminated by solution. The development of chlorite or mica slate, with the characteristic cleavage, is thus a change in the direction of molecular differentiation into:

- (a) monad-oxides combined with Al_2O_3 , SiO_2 and water; this constitutes secondary mica, especially sericite;
- (b) diad-oxides combined with Al_2O_3 , Fe_2O_3 , SiO_2 , and water; this constitutes secondary chlorite;
- (c) and, from chemical considerations, free silica; this appears as free secondary quartz.¹

Accessory minerals present in slates are probably largely developed from the excess ions over what are required for the formation of the principal constituents mentioned above², or they represent impurities in the sedimentary clay, mica and other minerals, which have been eliminated by recrystallization.

A further factor operating in the same direction is osmotic pressure, as set forth in the well-established principle of Soret³, which states that in a solution having a thermal gradient, the solute will travel in the direction of the gradient and toward the cooler parts. Some heat is unquestionably developed in connection with increased pressure at the point of contact between grain and grain. For any single grain a thermal gradient is thus established, and hence from thermal considerations it is wholly likely that the molecules of the solute will move away from the part of the grain under compression and thus migrate in the direction of *least* stress (or of definitive grain elongation). In the direction of least stress, therefore, and of greatest grain elongation, there will be, for thermal reasons, a concentration of solute molecules, which promotes local precipitation and hence furthers grain elongation in that direction.

Those porphyroblasts, such as Sander's and Schmidt's "querglimmer," Behre's chlorites, and Born's unusual biotites,⁴ are perhaps due to later shear with changing stress-directions. They may, however, also represent porphyroblasts that have grown after the development of slaty cleavage in a rock which, through recrystallization, has obtained a very high density and hence has its internal stress essentially equal in all directions; this circumstance favors crystal growth according to fortuitous orientation, as though the crystal nucleus had been suspended in solution. Thus porphyroblasts represent a later stage than the first development of slaty cleavage, although, as Sander and others have shown, still later changes may reorient both cleavage and porphyroblasts.

Schmidt⁵ has very properly pointed out the very great importance of

¹ Brammell, Alfred, Reconstitution processes in shales, slates, and phyllites: Mineralogical Mag., vol. XIX, p. 223, 1921.

² Brammell, Alfred, *op. cit.*, p. 224.

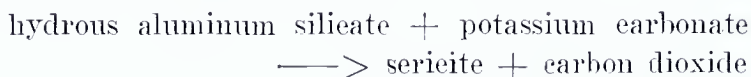
³ Soret, Chas., Sur l'état d'équilibre que prend, au point de vue de concentration, une dissolution saline primitivement homogène dont deux parties sont portées à des températures différentes: Ann. Chim. et Phys., ser. 5, vol. XXII, p. 297, 1881.

⁴ Sander, Bruno, Gefügekunde der Gesteine, Julius Springer, Wien, 1930, fig. 84, p. 208; Behre, C. H., Jr., Slate in Northampton County, Pennsylvania: Pa. Geol. Survey Bull. M-9, p. 89, 1927; Born, Axel, Ueber Druckseheifung im Varistischen Gebirgskoerper: Fortschritte der Geologie u. Palaeontol., vol. VII, no. 22, plate VII, fig. 7, 1929.

⁵ Schmidt, Walter, Gesteinsumformung: Naturhist. Mus. in Wien, Denkschrift., Bd. 3, pp. 45-50, 1925.

crystal direction in its bearing upon crystal growth and deformation. Very probably recrystallization operates vectorially in selecting for growth favorably oriented crystal nuclei, thus representing a combination of Riecke's principle and space lattice selection. Not only does the vector affect precipitation, however, by inducing the growth of the favorably oriented crystals, but it also influences solution as mentioned above and as first strongly urged by Schmidt.¹ Early rotation of nuclei may also contribute to crystal parallelism.

The question of the initiation of crystallization is especially difficult and may justifiably be saved, as here, till last. Probably every clay has to start with enough mica to serve for "seeding" muscovite crystallization. For chlorite, however, this statement does not apply. The movement in the direction



or the analogous formation of chlorite is probably conditioned by a thermal change; it is an endothermic reaction,—as empirically indicated by the sericitization and chloritization in contact metamorphism. In this case "seeding" is probably not even necessary; should it take place, however, then the general elongation of sedimentary mica flakes parallel to the bedding will furnish a ready explanation for the frequent growth of secondary mica and thus also development of schistosity ("S-planes") parallel to the bedding, as so greatly emphasized in the writings of Schmidt and Sander under the name of "Abbildungskristallisation."

3.—The role of the overburden is recognized by all investigators. At least a moderate cover is necessary to insure the growth of slaty cleavage; in its absence the rock yields by fracture or along shear planes, giving faults, or it flows without recrystallization. In Pennsylvania the cover above the Devonian shales of Carbon County was between 6,580 and 15,850 feet and it may have been between 12,290 and 21,545 feet thick above the Ordovician shales of the Lehigh-Northampton district, according to Ashley.² Even at the relatively shallow depths at which slate may be formed, slight differences in overburden may determine whether the metamorphic product shall be clay slate, slate, or phyllite.³

Nevertheless, simple load or "static" metamorphism does not in general effect the change from shale to slate. It is safe to say from known facts that static load alone has not given origin to any of the commercially worked slates of the United States. In American literature in general static metamorphism is but rarely called upon to explain slaty cleavage⁴ and abroad the emphasis is placed more and more upon internal movements of rocks and less and less on simple gravity stresses. Though it is recognized that static pressure may induce changes in mineral composition, especially in the case of hydrated minerals,⁵ the development of slaty cleavage does not represent a very high degree

¹ Op. cit., p. 50.

² Oral communication, 1931.

³ Born, Axel. Ueber Druckschieferung im varistischen Gebirgskörper: Fortschritte der Geologie u. Paläontol., vol. VII, no. 22, esp. p. 331, 1929.

⁴ For example, Daly, R. A., Metamorphism and its phases: Geol. Soc. Am., Bull., vol. 28, pp. 400-406, 1917.

⁵ Behrend, Fritz, and Berg, Georg, Chemische Geologie, Ferdinand Enke, Stuttgart, 1927, p. 529.

of metamorphism and is apparently always connected with folding and lateral thrust, rather than with very deep burial.

It is probable that the amount of differential pressure necessary to produce reaction between the kaolin (or allophane) and potassium carbonate in the forming of sericite, might be determined by a rigorous thermodynamic treatment, given certain values, not as yet determined, of the constituents. What is necessary in any case is a pressure differential, for this alone can produce the reorientation required, whether by physical or chemical means. Conceivably, however, a *differential* value for horizontal and tangential stresses equal to that which frequently develops slaty cleavage might exist without resulting in such cleavage; this may well have been the case, for instance, where shale has been folded. The difference between plastic flow and incompetent folding on the one hand and cleavage development on the other must lie in the high value of the minimum (downward) pressure required to produce the latter. Until that value is attained a differential between tangential and downward pressure produces only shear along well-separated planes or folding with fracture or with plastic flow,—not recrystallization. The reason for this behavior is obvious from a consideration of temperature-pressure-solubility curves.

If temperature is plotted against pressure for a solution exactly at saturation, the concentration remaining constant, it is found that increases in temperature and pressure are approximately reciprocal. Increases in temperature with constant pressure increase the solubility; from the principle of Le Chatelier, solubility is also increased with a rise in pressure, even at constant temperature, because solutions occupy a smaller volume than the sum of the volumes of solvent and solute. As depth is gained, therefore, solubility is raised, partly because the total pressure regardless of direction is increased, partly because the temperature rises according to the geothermal gradient. If, with great depth, the differential between static (vertical) pressure and dynamic pressure (tangential "thrust") is slight, cleavage cannot become well-developed, but crystalloblasts may be conspicuous. If the *differential* stress could be increased, orientation would grow more and more perfect, and finally good slaty cleavage would be attained.

Since most folding is carried on at relatively shallow depths, the true schists are generally formed from preexisting slates, and this only as more and more sediments accumulate above them or as overthrusting or close folding contribute to the superincumbent rock mass; hence porphyroblasts commonly appear comparatively late in the development of a highly metamorphosed rock and slaty cleavage precedes them.

There are difficulties in this concept which will occur to the critical reader, especially in respect to the mode of overburden increase in connection with the mountain folding which generally initiates metamorphism. These, however, cannot be considered here.

4.—It is especially difficult to evaluate the time factor in the development of slaty cleavage. "Flowage" of a sort can be induced in rock under the mere transverse stress developed by the weight of the rock itself, if sufficient time elapses; witness to this is borne by the "sagging" of doubly suspended limestone and marble grave covers. Just how this specific ease of "flowage" is accomplished—whether by gliding, recrystallization or intergranular shear—is not known. Lateral thrust in the surface of the earth is powerful, yet slowly applied; given

time "flowage" takes place where sudden movements would induce fracture; beautifully sigmoid slate flakes found in some Lehigh County quarries bear out this statement. Corresponding microstructures are seen even in minerals with such high crushing strengths as quartz, deformed but unfractured crystals of which are frequently found in slate. Time is thus of prime importance in determining the forms which metamorphism will induce in clayey sediments.

Although quantitative expressions for the specific case of slate, and, in fact, of rocks in general, are wanting, a brief discussion of the factors affecting the rate of metamorphism is justified. The physical effect of time may perhaps be condensed into the statement, already presented in other form, that a long time interval permits internal readjustment of the nature of plastic flow. Uniform "surrounding pressure" of high values favors "flowage" in the sense of adjustment by gliding, rotation, and the like,—physical adjustments of molecular or crystal size, as opposed to rupture affecting rock masses as a whole; this was most recently demonstrated by Karman.¹ In short, pressure and time are both functions of non-ruptural deformation.

Recrystallization, being conditioned by time, is also conditioned by factors affecting time. Diffusion, an essential in recrystallization, requires time for its completion. For sodium chloride at molar concentrations and 15°C., the rate is only .94 sq. cm. per day. For the silicates it is vastly less. Its rate is further reduced if it has to operate, as it does in this case, through solid rock. Yet it should be recalled that the molecular movement required for recrystallization is in itself minute per molecule, as mica crystals in true slates are seldom over .02 mm. in length and individual molecules can scarcely have moved a much greater distance. Moreover, highly ionized salts diffuse more rapidly than compounds that are only slightly ionized. The fact that in recrystallization one of the salts entering the reaction is potassium carbonate favors relatively rapid diffusion. On the other hand, unless a closed system is assumed, the readjustment of cleavage to fit new directions must necessarily be a much slower process, because it deals with weakly ionizing salt (sericite and chlorite) or colloids (silica). Finally, diffusion rate is greatly increased with concentration, and concentration of the molecules of recrystallization must be high indeed. Also diffusion rate is greatly increased with temperature.

Perhaps, then, all that may be derived from a consideration of physico-chemical evidence regarding the time required for recrystallization, is some impression of its great length. This is heightened when the geologic time scale is considered. The time periods during which orogeny acted in developing slaty cleavage in various slate belts of the earth, were always long. If it be assumed that the latter half of the Permian was consumed in Appalachian orogeny, then, based upon Seuchert's data,² the time required for the folding and metamorphism of the Devonian shales of Carbon County, Pennsylvania, amounted to 7,500,000 years; this figure is probably too high. Again, if, as the writer thinks, the uppermost Ordovician, lacking in eastern Pennsylvania, represents the Taconic period of orogeny, a figure of 7,500,000 years is arrived at for the time interval during which the Martinsburg

¹ Karman, Th. von, *Festigkeitsversuche unter allseitigem Druck*: Zeitschr. des Vereins Deutsch. Ingen., vol. LV, pp. 1749-57, 1911.

² Pirsson, L. V., and Schuchert, Charles, *Introductory geology*, Part II, Wiley and Sons, New York City, 1924, p. 485.

shales were folded and altered to slates. These estimates have no great value, since they include the earlier adjustments by folding as well as the later formation of cleavage. They do, however, give the order of magnitude of the time involved in metamorphism.

A second question may be raised: Is recrystallization contemporaneous with deformation or is it a distinctly later process? There has been much discussion of this subject, well summarized by Grubenmann and Niggli.¹ In general, to judge by petrographic appearances, cleavage development seems to be continuous with plastic deformation, yet, for any specific part of the rock mass, cleavage must be later and fairly definitely separated in time from plastic deformation. The fact that crystals lie with long axes transverse to and largely actually crossing individual bedding planes, strongly suggests such a definite change from folding with plastic deformation to cleavage with mineral growth. Sericite flakes that are straight where the beds are curved by folding, as figured by Sander, lead to a similar inference.²

5.—The development of typical schist by the regional metamorphism of slate is due to one of two processes,—either heavy recrystallization or subsequent movement. When the newly formed mica or chlorite flakes become large enough, mica or chlorite schists result; impurities eliminated in this recrystallization may combine to form new and important accessories. If contact phenomena are associated with the regional pressure, new minerals may grow to the extent that the rock changes noticeably, not only in mineralogical character, but in chemical composition as well.

Renewed or increased compression may also produce a schist through processes more nearly related to mechanical than to chemical changes, however. This results predominantly in the development of "slip cleavage" or false cleavage, described elsewhere in this report. Not all slip cleavage is a preliminary stage in schist formation; there may be purely local conditions for its appearance, and in this case the term schist cannot justifiably be applied to the entire formation. But if over a region as a whole false cleavage predominates, the slaty beds affected will already show many of the characteristics, especially the crumpling, of a schist. Factors favoring the development of false cleavage are:

- a.—A marked change in the direction of compression with respect to the previous direction, especially if such pressure is so abruptly applied as to preclude readjustment to the new direction.
- b.—A rotational or shearing stress, again too rapidly developed to permit readjustment of cleavage. This cannot be distinguished with certainty from (a); when the cleavage is deformed along limited shear planes, however, the presumption is that shearing stress, rather than general change in direction, is the cause.
- c.—Variation in composition, as from originally shaly to originally sandy beds; this promotes the development of gliding planes parallel to the bedding in case of subsequent resumption of compressive stress, since recrystallization is generally poor in the sandy layers, which thus still retain a unity of movement.

¹ Op. cit., pp. 235-239.

² Op. cit., p. 262.

WEATHERING OF SLATE.

In addition to the early weathering which yields the color changes already described on pages 19-20, long continued attack by air and water produces more fundamental and critical changes that affect the workability and utilization of slate. These may be briefly discussed under two headings,—physical changes and chemical changes.

Physical effects of prolonged weathering. In general the earlier color changes amount to a paling, coupled, in the presence of iron carbonates, oxides, or sulphides, with a faint browning through the formation of limonite. As the process goes further, the colors become lighter and lighter, or are tinged progressively more and more with brown. Thus in extreme weathering the blue-gray slates of the Lehigh-Northampton district change first to a lighter gray, then to brownish-yellow, and finally to light ocher; the very dark blue-gray slates of the Peach Bottom district assume a peculiar olive-brownish-gray and finally alter to a deep brownish-red clay; and green and red slates assume various shades of chocolate-brown or ocher, yielding yellowish or reddish clays. These extensive color changes require thousands of years for completion and are not to be confused with the color-aging already referred to.

While such color alterations are going on, corresponding structural changes may also be observed. If the slate is exposed at the surface of the ground, water slowly works its way by capillarity along cleavage planes; should a frost ensue, the crystallization of the water into ice pries the slate apart. Even without freezing, however, and indeed in some cases through the action of sudden or unequal heating, rather than chilling, the cleavage planes slowly part in close spacing, and lamellae, scarcely thicker than heavy paper, separate from the surface of the block. Though first still attached to that surface at one end, these thin flakes ultimately spring off from it, giving an appreciable increase in volume and entirely spoiling the slate for use. Usually one edge of the block shows this separation along cleavage planes exceptionally well. It is this tendency to exfoliation along the cleavage that makes it desirable to leave the slate in the ground, where it will be protected by a soil or rock cover, or beneath the level of the quarry water until it can be removed and immediately split to the desired thickness.

Physical disintegration by exfoliation parallel to the cleavage is often especially noteworthy where carbonaceous layers or "ribbons" cross the beds. These "ribbons" also resist the abrasive agents of weathering (such as the effect of sand in a stream bottom) less well than do the non-carbonaceous layers.

As weathering proceeds, a marked softening of the stone as a whole is generally also observable, coupled in many cases with the development of a talcose or greasy feeling and luster.

Mineralogical and chemical changes on prolonged weathering. This subject has been studied by Dale, Merrill, and Shearer,¹ chiefly by comparing the fresh slate in various districts with its residual soil. On the basis of the changes involved, slate may be separated into two classes. The first of these includes the more common carbonate-rich slates, like most of those of Pennsylvania, New York, and Vermont. When these break down through the action of air and water, they lose

¹ Dale, T. N., *Op. cit.*, pp. 53-55; Merrill, G. P., *Rocks, rock-weathering and soils*, Macmillan, New York, pp. 213-215, 1906; Shearer, H. K., *The slate deposits of Georgia*: Ga. Geol. Survey Bull. 34, pp. 20-22, 1918.

especially their carbonate constituents, because these are the more soluble minerals. The effect is to give a relative increase in silica, the alumina remaining essentially constant. This result is typified by analyses B and C in Figure 22, representing respectively fresh and heavily weathered slate from the Lehigh-Northampton (Pa.) district¹ and fresh and partly decayed slate from Rockmart, Ga.²

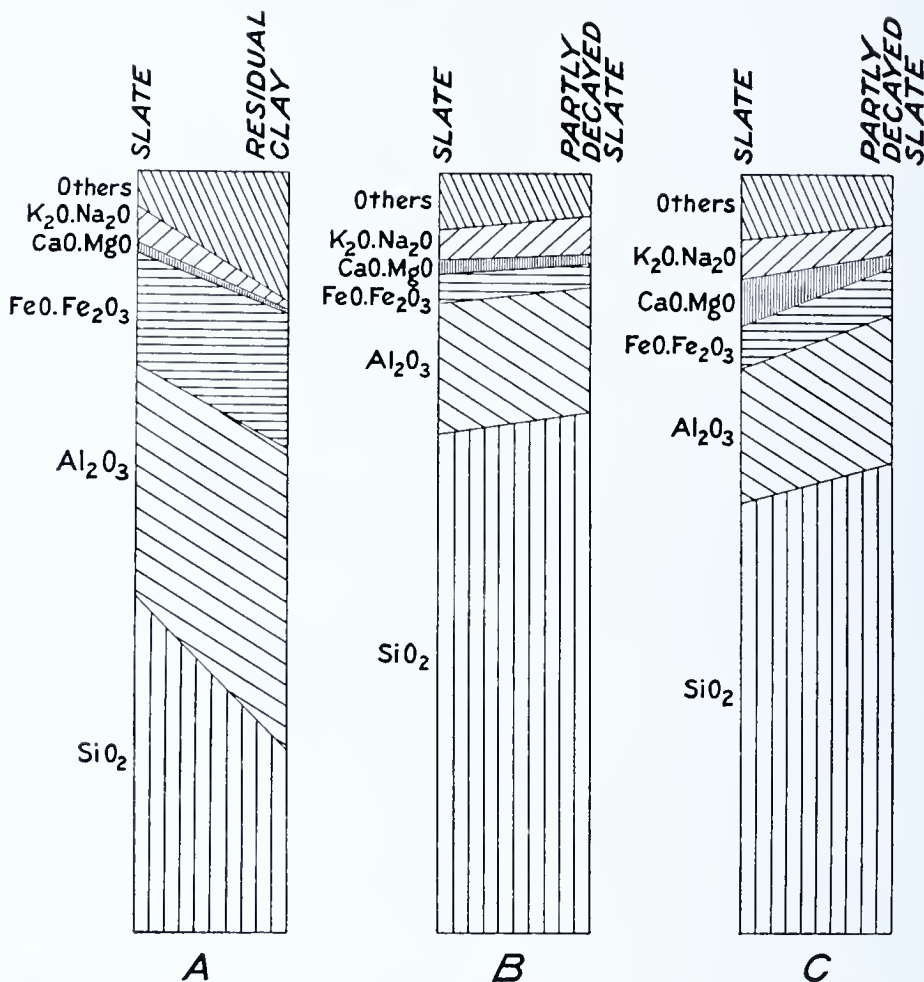


Fig. 22. Diagram of chemical changes produced in the weathering of slate. A, Peach Bottom slates (after Merrill); B, Lehigh-Northampton slates (after Dale); C, Georgia slates (after Shearer).

Extensive weathering of slates of this general type, according to the studies of Dale, Shearer, and the writer, involve the following fundamental changes:

- 1.—Removal of carbonates, any iron present in carbonate minerals being converted to limonite.
- 2.—Oxidation of iron sulphides, with deposition of the iron as limonite.
- 3.—Oxidation and removal of carbon present in the form of graphite or organic compounds.

¹ Dale, T. N., op. cit., p. 54.

² Shearer, H. K., op. cit., p. 21.

- 4.—Decomposition of silicates (feldspar, sericite, ehlorite); the alkalis and alkaline earth are removed as carbonates, and the iron remains as limonite.
- 5.—In some cases, where the end product is a light-colored clay (see analysis B in Figure 22), limonite is also removed. Why this change is well-shown in some analyses and not in others is not clearly understood, but the difference is probably related to the stage of weathering which the "clay" represents. Limonite is most probably not removed in relatively large quantities prior to the last stages of decomposition.

The second type of weathering is shown in analysis A, Figure 22, which represents fresh slate and the corresponding residual clay from the Peach Bottom district¹; this slate is from Maryland, but is equally representative of the Pennsylvania part of the district. Here the striking changes produced by extensive weathering are the decrease in silica, the alkaline earths, and the alkalis, and the relative increase in alumina and iron. However, at least a part of the silica decrease in this instance is certainly due to the fact that the residual clay in analysis A has suffered more complete leaching than the only partially decayed slates of analyses B and C.

In comparing these two types of weathering, reference should be made to the mineral constitution of the original slates.

QUARRY WATER.

Summary. Water enters the quarry in five ways:

1. Along the sides of the quarry, especially at the corners; in this case it generally represents surface run-off.
2. Along the bedding planes, particularly where there are openings between successive beds.
3. Along open joints.
4. Along cleavage planes, notably where stringers of quartz or calcite laid down parallel to the cleavage were later in part dissolved away, so as to leave gaping openings.
5. Along shear or fault zones.

A few illustrations of these modes of ingress may be cited. About one mile west of Bath, Northampton County, on the Dannersville road, is a school-house. A small opening has been made on a side road 1000 feet east of the school. In the east wall of this quarry and ten feet above its floor is a zone about two inches wide and parallel with the cleavage; this is now only partly filled with quartz, the rest of the filling having been largely dissolved away. Here and there in the crevice, traces of the cavernous quartz are still to be seen. This crevice is ice-filled long after snow disappears in the spring, and evidently contributes quarry water.

In the lower level of the New York quarry, five miles northeast of Bangor, Northampton County, is a zone of movement approximately parallel to bedding and bounded by a calcareous bed showing slickensides and striae. Water enters freely along this zone and apparently connects with the ground water beyond the quarry, as the ingress of

¹ Merrill, *op. cit.*, p. 214.

water here is said to have been synechronous with the flow from a nearby well. It appears that the shattering of the rock by the drilling of the well produced a subterranean passage-way between the general ground water and the open shear zone mentioned.

In the Tinsman quarry at Wind Gap water enters in three ways: (1) along the sides of the quarry; (2) along bedding planes, especially near the surface; (3) especially prominently along joints. Some joints are partially sealed by ealeite, but many are open, and even the small ones deliver much water. From one very narrow joint a gallon of water escaped in sixteen minutes.

In an impervious rock such as slate, water in quantity can travel with rapidity only along open joint, cleavage, and fault planes. "Perched" water tables thus develop, with the accompanying hydraulic pressures. Because of such "perching", adjoining quarries frequently show markedly discordant water levels. Thus at Slate-dale, Northampton County, the water level in two quarries not more than 150 feet apart and both long abandoned, shows a difference of 15 feet. Such "perched" water seeks any opening that will allow it to sink to ground water level. Hence quarries are sometimes suddenly inundated as operations expose an open cleavage crevice, joint, or partially shattered surface of shear.

Effect of water on quarrying. Besides hindering work directly by flooding the quarry, water frequently becomes a serious menace in that it induces "slides" or avalanches of rock from the quarry walls. It moistens shattered zones and thus forms a natural lubricant along which large pieces of the walls may move into the quarry in mass. In this way almost half of one side of a large quarry in the "hard" belt of Northampton County fell into the opening; three men were drowned in the surge of the quarry water produced by the fall.

In the winter seepage water freezes and makes footing uncertain in the quarry bottom; where this has a steep slope, a fall is serious.

Some advantages, however, are contributed by quarry water. It keeps the slate on the quarry floor saturated, thus reducing the extremes of temperature to which it might otherwise be exposed. When slate in large blocks dries out completely, there is a tendency for it to break open along the cleavage; flexibility in splitting is thus lost and quarry waste is increased. For these reasons quarries that are to be shut down temporarily are frequently flooded on purpose.

Artificial drainage. Surface run-off may be diverted from the quarry by a trench that circumscribes the opening at the surface. Quarry water entering through walls or floor is commonly drained to the lowest-lying corner and pumped from this sump. Lately an improvement has been introduced. At a point outside the walls and in the direction from which the water naturally flows toward the quarry (that is, presumably, up the cleavage dip), a six-inch hole is drilled to such a depth that it pierces the water-bearing cleavage, bedding, or joint planes. Charges of dynamite are fired in the hole, so as to shatter the rock and induce greater water delivery into this opening. The water is then pumped from this drill hole. The method was practiced with success at one of the Jackson Bangor quarries near Pen Argyl and has been well described by Bowles.¹

¹ Bowles, Oliver, Recent progress in slate technology: U. S. Bur. Mines Repts. of Investigations, Serial No. 2766, p. 6, 1926.

THE VALUATION OF SLATE PROPERTIES.

Very little has been done either in Pennsylvania or elsewhere in the United States, toward developing methods for slate quarry valuation. The problem to be faced may be either (1) what is the value of slate land to a purchasing company in advance of any operations on the property in question or (2) what is the probable value of a developed quarry plus any equipment, as it stands. These two cases must be separately considered.

VALUATION IN ADVANCE OF OPENING.*

Basis of valuation. As a basis for determining the present value of slate land it is generally necessary to find the market value of similar land adjoining that in question. From this base value, the reflected value of the land to be appraised may be found.

There are various methods for determining the market value of slate lands, dependent upon the circumstances in individual cases. Three chief sources of information are available to the appraiser; namely, sales, opinions, and assessments.

It has been found by the Bureau of Valuation of the United States Interstate Commerce Commission, during nearly ten years of the prosecution of its work, that the first source, sales, is by far the most reliable indication of true market value. Sales are tangible; all the facts pertaining to a sale can generally be ascertained and stated with certainty. Not all sales are usable or applicable, but the weight of the authority of court decisions is that bona-fide sales of property are the most reliable indication of market value. Opinions of slate operators, in the absence of sales or other information, offer a guide in arriving at a conclusion of value. But there are many pitfalls in using opinions, and the men selected should be thoroughly familiar with values in a given territory and capable of rendering an impartial expression of opinion. Assessments generally cannot be relied upon without some other check. Assessed values are rarely, if ever, true values, although the law in many instances requires that property be assessed at true values.

In evaluating mineral land it is generally desirable to establish the worth of land upon the basis of naked land value plus minerals. To do this, the presence of workable slate must be determined. The answer to the question as to the mere existence or non-existence of slate is not difficult to find; available geological maps should show graphically the location of slate deposits in relation to the land appraised.

On the other hand, the actual market value of slate deposits, in the ground, is not so easily found. At the beginning of the industry in most slate regions, there was considerable prospecting and "wild-catting." In the enthusiasm of pioneer development, fabulous prices were paid for presumably slate-bearing lands. When the fever was on, every man's farm situated in a slate region was looked upon as a potential fortune because of the slate presumed to be contained in the ground. Many of these early ventures turned out to be failures. Hence original estimates and prices paid in the 19th century are

*This summary of land valuation in advance of opening is slightly altered from a personal communication kindly prepared by Mr. Homer H. Kirby, of the Bureau of Valuation, Interstate Commerce Commission, who has been engaged in the valuation of state lands in Northampton County, Pennsylvania. The alterations consist of slight abbreviations which do not change the sense of the statement.

frequently too high. It is always pretty much of a gamble as to what will be the result after a costly quarry development has been made. For one reason or another discussed elsewhere in this report, it may transpire that the slate will be found to be useless for profitable commercial purposes, and this cannot be definitely known until after considerable development is carried out.

Conclusions. Because of the uncertainty surrounding any quarry development, it is the consensus of opinion of most of the men who are connected with the industry that slate lands are not worth anything in excess of bare land or surface value until proven. At the present time no operator or company will buy lands for quarry purposes until it has been proven that slate in commercially profitable quantities can be gotten out,—that is, until some preliminary development has been done. Until then the only value is that inherent in the surface of the land for farm or other purposes. Any other element of value is too intangible to determine.

VALUATION AFTER OPENING.¹

A far more dependable opinion as to the economic advantages of operating any given property may be formed after some quarrying on the property in question has been carried on. In rare cases, determined by the relative simplicity of geologic relations, judgment may actually be given with a large degree of certainty, if slate is merely being quarried on land immediately adjacent to the proposed new quarry site; but caution should be the rule in such instances, in view of the abrupt changes often observed in geologic conditions on two contiguous areas. The general headings under which questions may be considered are:

1. Intrinsic factors:
 - a. Value of land without regard to value of slate.
 - b. Value of standing machinery and quarry equipment.
2. Geologic factors:
 - a. Value of the slate under consideration as such,—e. g., original color, constancy of color, strength, smoothness of cleavage, etc.
 - b. Variety of uses to which this slate may be put.
 - c. Local geologic conditions affecting the value of the slate,—e. g., closeness of joints, curvature of cleavage, thinning of usable beds, etc.
3. Operation factors:
 - a. Overburden: Is cover thick or thin? Is it gravel or waste slate? Is it loose or consolidated? How remove the overburden?
 - b. Mode of operation: In general, is quarrying, tunnelling, or shaft mining to be employed? In detail, are structural conditions favorable to use of channeller, drilling and broaching, or the wire saw, etc.
 - c. Amount of usable slate available: In view of geologic con-

¹ See also an excellent general discussion in Eckel, E. C., *Building stones and clays*, chapt. XI, John Wiley, New York, 1912. A more specific but brief discussion is: Behre, C. H., Jr., *Geologic factors in the development of the eastern Pennsylvania slate belt*: Am. Inst. Min. & Met. Eng., Trans., vol. 76, pp. 398-410, 1928.

ditions and property controlled in depth and horizontally, and making allowance for the wastage inherent in quarry methods.

- d. Waste disposal: Space available and mode of handling waste.
 - e. Quarry drainage.
 - f. Climate, as affecting continuity of operations.
 - g. Labor conditions.
4. Transportation factors: Access to trunk railroads, to water haulage, and to truck haulage, over highways and roads; differential transportation costs to large consuming districts due to such access.
5. Demand factors:
- a. Present demand in general, on account of peculiar color, adaptability to certain uses, etc.
 - b. Special local demand,—chiefly on account of ready and cheap access.
 - c. Future demand as affected by new uses and by substitutes or competing structural materials.

The above table represents only an outline of the factors to be thought of in quarry valuation. The figures published by the Census Bureau,¹ indicate that the margin of profit for slate quarrying is below that for any other type of stone, and that the return on the invested capital is lower than for any other except limestone. Conservatism is thus imperative, and certain apparently insignificant factors may well make or break the quarry.

Certain of the factors listed vary so greatly from region to region that they fall into highly specialized studies and hence are omitted from what follows.

Intrinsic factors. The value of the land regardless of slate content has already been discussed above under "Valuation in Advance of Opening." The market value of standing machinery and buildings may generally be ascertained through consultation with engineers, machinery manufacturers, and quarrymen. These items are, of course, additive.

Geologic factors. The geologic factors are in general considered throughout this report, especially in the preceding parts of the section on "Economic Geology of the Slate"; for the effect of color, jointing, cleavage, and so forth, see the corresponding headings. Special care should be exercised that due allowance is made for local variations in color, strength, cleavage, bedding and the like. Perhaps the matter of pitch of fold axes is one of the most serious of these locally varying factors, because the least well understood by the quarrymen. In cases where uncertainty exists trenching or drilling may be resorted to.

Operating factors. The operating factors are at once the most difficult of solution and the most important. For considerations as to overburden, see the corresponding heading above (page 13) and the section on "Technology of Slate" (page 81); estimates of yardage of overburden on a section of the property that has not yet been opened may be made by trenching or post-holing.

¹ Fourteenth Census of the United States, 1920, vol. XI, Washington, 1919.

As to the amount of slate available, the sequence of beds should be carefully studied and an estimate made of the thickness of the workable beds *at right angles to bedding planes*. This, when multiplied by length of outcrop across the property, will give the "stratigraphic exposure" of each bed; the stratigraphic exposure in turn should be multiplied by feasible depth of quarrying, to obtain the total volume of a workable bed, due allowance being made for the dip of the layer. Although the quarrying of vertical or very steeply dipping strata might theoretically be continued as far as the dip persists, actual experience has shown that open pit operations at great depths are disproportionately expensive, and about 600 feet may be given as the maximum feasible vertical quarry depth.

After an estimate has been made as to the total slate available, a proper discount should be introduced to take care of loss through wastage in operations. Bowles states that the waste generally averages 70-90 per cent of the gross production of rock from the quarry;¹ rarely it may be cut down to 50 per cent. Good average factors for production of usable slate are 15 per cent of all rock quarried in the Peach Bottom district and about 22 per cent in the Lehigh-Northampton district.

Climatic conditions are similar in all of the Pennsylvania districts. It is customary to stop operations in the lower parts of quarries shortly after the first freezing weather in winter, which usually occurs in the middle of December and generally lasts until the middle of March. Quarrying is, however, continued in the upper parts of most openings, despite freezing. In mines operations are continuous. Quarrying is seldom stopped on account of rain and slate mining virtually never. Skilled labor is needed and labor costs are correspondingly high.

Mode of operation, waste disposal, and quarry drainage are considered under corresponding headings elsewhere in this report.

Transportation factors. In transporting slate, water haulage involves the least breakage and expense, and truck haulage the most. To avoid the latter, spur tracks connect with the nearer railroads, and their installation and maintenance cost must be faced. In transportation Pennsylvania quarries obviously have the advantage over those of Vermont and New York—their chief competitors—if shipping southward, but shipment far southward brings them into conflict with the Virginia producers. The special province of Pennsylvania producers should be the Central States.

Demand factors. Noteworthy factors affecting demand are probably color (in the case of roofing slate) and the increased use of slate for electrical insulation. The most important, however, is competition with other materials in structures. Slate competes with marble in stair treads and in interior panelling for decorative and utilitarian purposes, notably in showers, toilets, and the like. Slate meets competition from granule, asbestos, and shingle roofing. The relative demand for slate in these fields therefore is subject to constant fluctuation.

EXPLORATION

SURFACE EXPLORATION

Dale has already discussed the general methods to be used in exploring for slate when the rock is exposed at the surface.² If possible,

¹ Bowles, Oliver, The technology of slate: U. S. Bur. Mines Bull. 218, p. 81, 1922.

² Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, pp. 169-171, 1914.

a geologic map of the region should be obtained. This generally indicates the distribution of workable beds at the surface; and where other beds separate the desirable beds from the surface, vertical structure sections show to scale how deep a shaft or quarry must go to strike the strata sought.

In general, as Dale states, exploration along the strike is preferable. The strike may be indicated on the geologic map by means of strike and dip symbols; if not actually stated in some such manner, it may be inferred as being generally parallel to the contact between two formations in any region where the surface is only gently rolling or is actually horizontal; if the relief of the land is very great the strike cannot be inferred directly from the geologic map, but may be computed by geometric or trigonometric methods, given three points on the outcrop of any bed or contact.

It is not wise to assume infinite continuity in the character of a bed along its strike. To illustrate, if a quarry is successfully operated on a certain bed of slate, a neighboring quarry 300 feet away may well find the same layer profitable, but a mile farther off along the strike the slate may have become gritty or undesirable in other ways.

Qualities related essentially to bedding are likely to be somewhat variable along the strike, but features of later origin, such as joints, dip of the beds, perfection of cleavage, and the like are yet more prone to be so. Hence extreme caution must be used in hypothesizing similar structural conditions from quarry site to quarry site. A good working rule is to make no assumptions but always to carry out exploratory drilling or trenching in advance of actual quarry operations. Locally the natural trenching by streams may lay bare the slate of the surface. In all exploratory work it is desirable to obtain specimens of slate large enough for making the desired physical tests. It is essential also to secure specimens that have not suffered so much alteration as will make them not truly representative of the fresh slate.

If trenching is resorted to, it is generally preferable to cut the trench at right angles to the strike so as to expose as many of the slate beds as possible for a given length of trench.

SUBSURFACE EXPLORATION

The ideal method of carrying on subsurface exploration is by means of the core drill. Costs are less than actual quarry opening, and the drill core furnishes a fairly satisfactory clue to the qualities and structure of the rock penetrated; indeed, it is remarkable how clearly a well-kept drill core indicates subsurface conditions. No matter how experienced the slate operator may be, core drilling is the only method by which he may assure himself with reasonable certainty of the favorableness of stratigraphic and structural conditions in depth before actually opening a quarry.

Drilling should be done carefully, the cost being regarded as a legitimate expenditure comparable to development work in a mining operation. In Pennsylvania it has been practiced especially at Slatington, where close folding makes the structure very irregular and where it is desired especially to open only certain exceptionally thick beds. Here shot drilling has been the most common practice. A few of the more experienced operators have from time to time contracted to drill exploratory holes on land of which the development was contemplated, thus carrying on a very useful type of consulting work.

Vertical angle drilling. Dale advocates drilling at a vertical angle of 45° to the cleavage dip, so that the core will split into elliptical pieces sufficiently larger than diameter of the core to be conveniently tested.¹ This method would doubtless be wholly satisfactory in the Peach Bottom district and perhaps also in the neighborhood of Pen Argyl and Bangor, but at Slatington the most essential knowledge is the thickness of the beds which would be penetrated in the opening and for this purpose it is preferable to drill at right angles to the dip of the bedding, regardless of cleavage. In most regions one drill hole judiciously placed will furnish sufficient information as to thickness of beds; these data may then be supplemented with additional drillings aimed at testing the physical properties, especially the excellence of cleavage, of the slate, thus accomplishing the object mentioned by Dale.

Horizontal bearing of drill-hole. When the maximum information as to the character of the beds is desired, it is best, if the holes are not actually vertical, to so set the drill that it penetrates the beds in a direction normal to their strike. If the bedding is indistinct (e. g., in the Peach Bottom district) or does not seriously affect the success of quarry operations (e. g., in the Lehigh-Northampton "hard" slate), the drill holes are best directed vertically and in that case the horizontal angle between strike of bedding and direction of drill obviously becomes nil.

Spacing of drill holes. The spacing will be governed in large part by the shape of the property to be tested and the expenditure set aside for testing. No general statement can therefore be made as to the distance between holes. The simplest pattern in ground plan is to lay out the holes either:

1. In a line or lines at right angles to bedding strike,—in Carbon County and in the Lehigh-Northampton "soft" slate belt and its westward extension into Berks County.
2. In a line or lines at right angles to cleavage strike,—in the Peach Bottom district and in the "hard" slate belt of the Lehigh-Northampton district.

Orientation of drill cores. The writer has found that the combination of grain and cleavage directions may be used to orient roughly and check the orientation of drill cores, should these become turned in the drilling. In any district cleavage and grain generally have a constant trend. Thus at Slatington and Pen Argyl the cleavage strike is almost always northeast and the grain trends northwest. The cylindrical core may be placed in such a position that its cleavage strike is northeast; it may also be chipped a little, until a grain fracture plane appears on the surface; when the cleavage is northeast, the grain is northwest. Should the trends of these structures differ from the directions given above, the grain direction is the more dependable, as the cleavage strike is, at least in exceptional cases, variable. The method will serve in all instances where the core has not had top and bottom reversed.

Determination of actual thickness of beds. The apparent thickness of slate beds, as shown in the drill core, is seldom the *true* thickness.

¹ Dale, T. N., op. cit., p. 171.

Where there is interest in the *actual* thickness of beds (e. g., in the "soft" slate of the Lehigh-Northampton district) a method of converting the apparent thickness must often be applied.

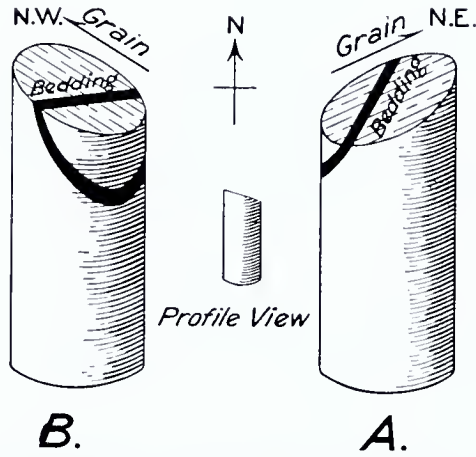


Fig. 23. Use of grain in orienting drill cores: A, incorrect orientation; B, correct orientation; cleavage dips south in A, but grain trends northeast; cleavage dips south and grain trends northwest in B.

Obviously, if the drill is driven at an angle of 90° to the beds, the actual thickness of any bed is equal to its apparent thickness as measured along the drill core. If, however, the drill core was taken at an angle of, say, 70° to the beds, a factor must be allowed for because the apparent thickness is clearly greater than the true thickness, as is shown in Figure 24. The actual thickness may be obtained by computation through the formula

$$\sin a = \frac{t}{l},$$

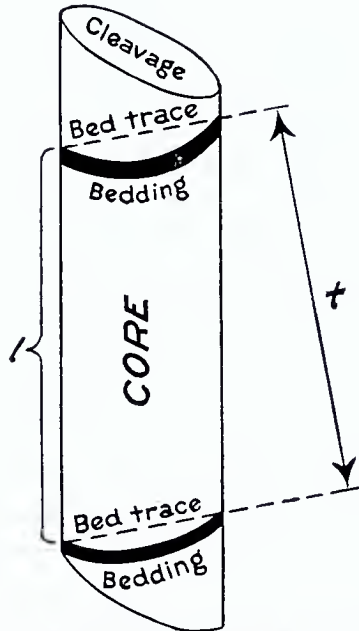


Fig. 24. Use of core obtained by drilling at an angle other than 90° to the beds, for computing actual thickness between beds.

in which a is the vertical angle between the bedding and the drill hole, l is the distance from top to bottom of the bed as measured along the core, and t is the true thickness of the bed. Or the true thickness may be obtained by actual measurement if a ruler or scale is laid along the drill core (or its plotted equivalent) so as to make an angle of 90° with the dip of the bedding as shown in the drill core.

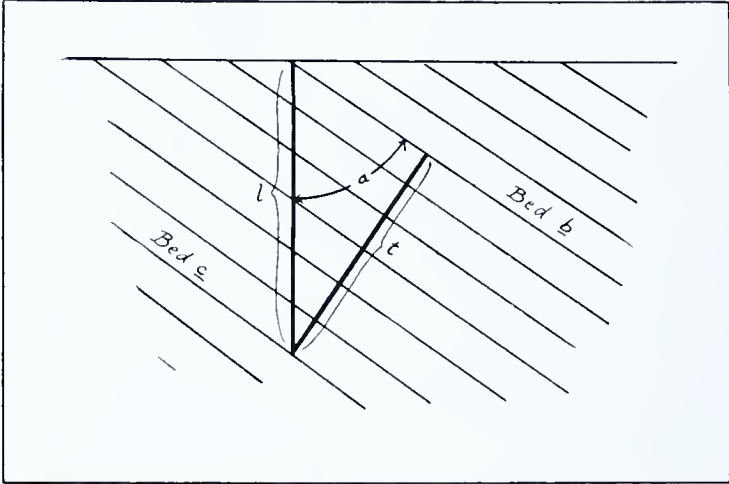


Fig. 25. Method of estimating depth of any desired bed c, when bed b is recognized at the surface and actual thickness t separating the two beds is known.

Conversely, the apparent thickness l to be expected in a projected drilling may be estimated if the actual thickness is known by substi-

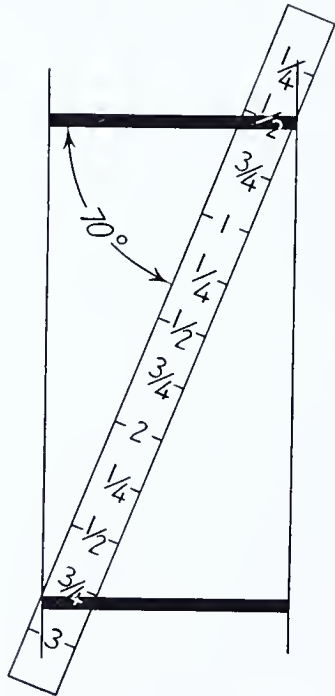


Fig. 26. Method of using thickness charts in estimating apparent thickness of beds.

tuting the actual thickness for t in the formula given above, or by placing the ruler across a thickness diagram in such a way as to make with the bedding planes the angle which the drill in the projected hole will actually make with the bedding.

These methods may be applied to the tables of thicknesses given in the section entitled "Detailed Stratigraphy of the Soft Slate", on pages 187-191. The figures arrived at may call for qualification, as indicated on pages 185-186.

Determination of required depth of drilling. When a recognizable bed is exposed and a knowledge of the depth for drilling to strike a deeper bed is desired, the formula

$$\sin a = \frac{t}{l}$$

may again be used. In this case l is solved for, t being given and the angle a being obtained by observation at or near the locality to be drilled.

Examination of the drill core. From what has been said elsewhere in this report regarding the desirable qualities in slate, the reader will readily infer the things to be looked for in the sample core. Mention may be made, however, of the impurities to be warned against. Quartz "knots" or carbon "flakes" should be watched for. Of special importance is curved or curly cleavage, as is also false cleavage, appearing as tiny rulings or incipient fracture planes on the true cleavage. Quartz and calcite veinlets, because they are usually found near faults or fractures, where cleavage is bent or shattered, are criteria that suggest conditions unfavorable to development. Near faults, the white quartz or calcite veins and crystal-filled openings are especially common: an excellent illustration of a core showing such a fault zone is to be seen in Plate 13, A.

Dale suggests applying to sections of the drill core various physical tests as well; the core samples may also be used for chemical analysis or for study with the microscope. For such methods of examination, the reader is referred to the appropriate sections of this report.

THE TESTING OF SLATE.

In America Williams,¹ Baker and Davidson,² and Merriman³ were the first to give careful technical attention to the testing of slate. The work of Merriman deserves particular mention. Merrill⁴ also presented various methods for testing slate under the general heading of building stone testing. In 1914 Dale⁵ republished his earlier summary of the physical tests commonly applied to slate. Subsequently Committee D-16 on Slate of the American Society for Testing Materials has attacked the matter of tests with special care, and has presented its findings periodically before the Society.⁶

¹ Williams, J. F., Tests of Rutland and Washington County slates: Van Nostrand Eng. Mag., vol. XXXI, pp. 101-103, 1884.

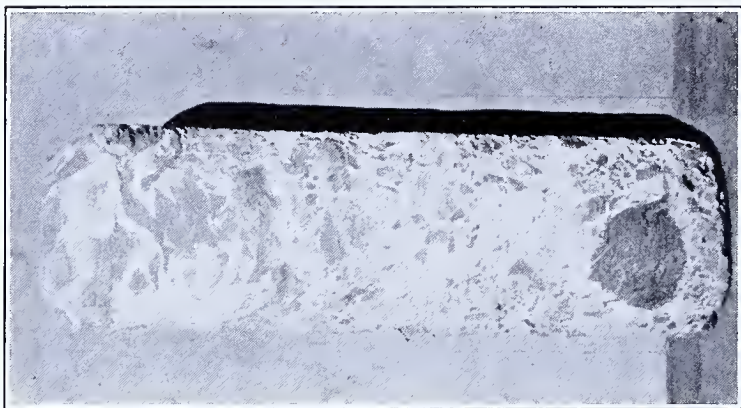
² Baker, E. R., and Davidson, A. R., The strength and weathering qualities of Vermont roofing slates: Rept. of Vermont State Geologist for 1911-1912, pp. 230-231, 1912.

³ Merriman, Mansfield, The strength and weathering qualities of roofing slates, with discussion: Am. Soc. Civil Eng., Trans., vol. XXVII, pp. 331-349, 1892; vol. XXXII, pp. 529-539, 1894.

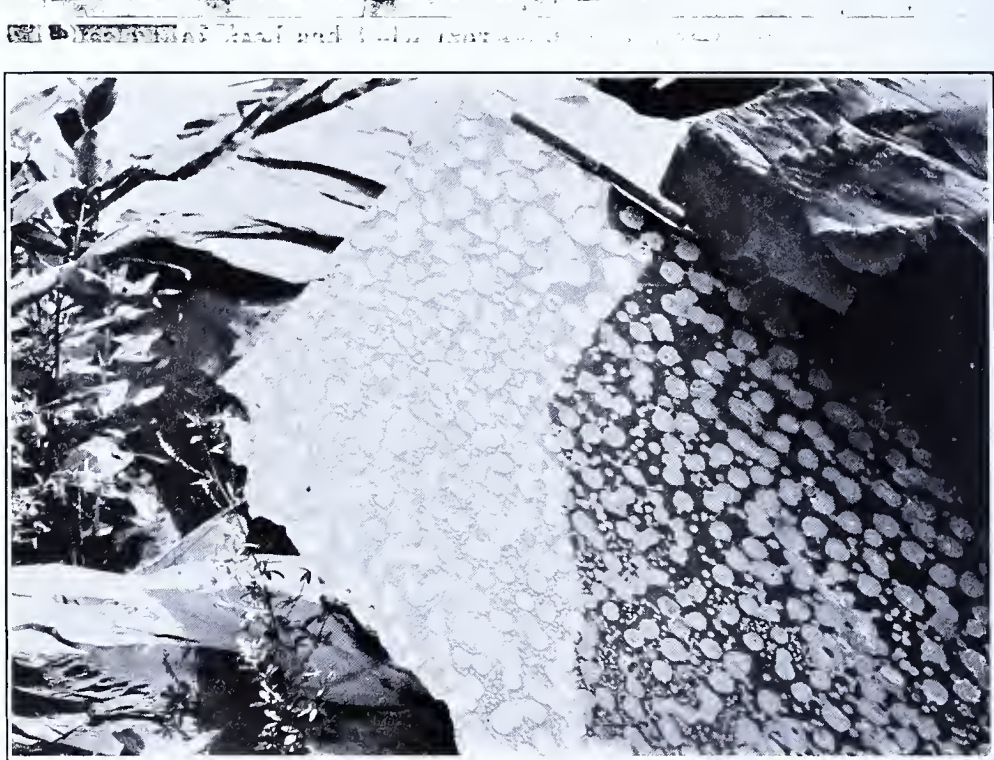
⁴ Merrill, G. P., Stones for building and decoration, John Wiley and Sons, New York, 1910.

⁵ Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, pp. 171-181, 1914.

⁶ Am. Soc. for Test. Mat., Proc. and other publications of the Society, Philadelphia.



A. Drill core showing fault breccia; from drilling near Slatington.



B. Calcite incrustations on joint plane of a quarried block, Slatington.

In Europe, Hirschwald¹ wrote the most comprehensive treatise on testing methods; Stiny² has also prepared a briefer statement on the subject, which, however, is considerably less detailed than that of Hirschwald and is not applied specifically to slate.

Much the most careful program of testing today is being carried on under the auspices of the American Society for Testing Materials through its associated agencies, especially the U. S. Bureau of Stand-

¹ Hirschwald, J., *Handbuch der bautechnischen Gesteinsprüfung*, Gebr. Borntraeger, Berlin, 1912; especially pp. 592-645.

² Stiny, Josef, *Technische Gesteinskunde*, Julius Springer, Wien, 1929.

ards, several of the large manufacturers and users of electrical and structural slate, and the universities represented on the committee mentioned.

The most important properties of slate for which tests are commonly applied are sonorousness, cleavability, grain, initial color, constancy of color, density, porosity and absorption, hardness or resistance to abrasion, toughness, compressive strength, transverse strength, elasticity, electrical resistance, and resistance to corrosion. So far as is known, tensile strength of slate is not tested, probably because in the usual uses slate is not subjected to tension capable of deforming the rock. Heat resistance is frequently important in warm climates, but no adequate test for this has yet been devised. Several types of special chemical tests have also been suggested but none have been generally accepted. Finally, mention should be made of mineralogical examination with the naked eye, the hand lens, and the petrographic microscope, which frequently sheds light on the various commercial properties of slate.

Sonorousness. Sonorousness may be determined while suspending the slate by a string drawn through a hole in one end of the slate or more commonly merely by holding the slate between the fingers or by balancing it on three fingers; the slate is struck a sharp blow with a hammer or mallet or with the knuckles of the hand; if it rings well, and lacks the metallic rattle that indicates a crack, it is thought to be good slate. The higher the degree of metamorphism, as a rule, the better the "ring" of the slate.

Cleavability. The test for cleavability is applied by the skilled slate splitter to the moist block of freshly quarried slate. The test consists merely in assuring the observer that the slate can be split with slate-splitter's tools to the normal thicknesses required by the trade without applying undue care.

Grain direction. Grain may be determined microscopically (see Plate 7, A). It may be determined physically by fracturing the slate. An accurate method is to drill a small circular hole on the cleavage surface, to place into this a conical-ended spike of circular cross-section, and then to tap the spike sharply; the slate will split most easily in the direction of the grain. The grain direction may also be tested for by the heat conductivity method of Jannetaz¹ or by electrical conductivity. Electrical conductivity or leakage is greatest in the direction of the grain and may be tested for as follows: one terminal of a resistivity meter of the type commonly used in testing leakage in slate is kept in a fixed position and the other is moved in a circle having a diameter of 4 to 6 inches; when the maximum leakage is recorded, a line is drawn between the two brushes and this marks the grain direction.

Initial color. No standard test has yet been devised. Hirschwald does not deal with color, nor have American research agencies developed any tests or scientific standards. In this country the nearest approach to a standardized color nomenclature is furnished by the Bureau of Standards classification of slate color.² Nine terms are utilized:

¹ Soc. Geol. France, Bull., 3d ser., vol. 12, 1884.

² Simplified practice recommendation R 14-2S, Roofing slate: U. S. Bur. Standards, p. 2, 1928.

| | | |
|------------|-----------|--------------------------|
| Black | Blue Gray | Mottled purple and green |
| Blue black | Purple | Purple variegated |
| Gray | Green | Red |

No attempt is made to define these terms accurately. Colored plates illustrating slate to which these terms are applied have been published from time to time but there is considerable leeway in the shades for which any of the above names are used.

A possible solution is the application of the color nomenclature of Ridgway's Color Chart or the modified form prepared by the National Research Council.¹

Constancy of color. For this, too, no tests have yet been devised. Presumptive evidence may be obtained from mineral or chemical analysis, especially the former, because certain minerals are known to alter rapidly. Empirical tests might well be performed, the time factor being balanced by accelerating the weathering process with exceptionally strong reagents.² Reference may also be made to pages 19-22 of this report.

Density. The essence of this process is weighing the slate in air and in water; the weight in air (i. e., its actual mass) is then divided by the difference between its weight in air and its weight in water (i. e., its volume). The chief difficulty of weighing in water is the removal of attached air; this is generally accomplished by boiling the rock specimen in water. Far more refined methods are those of Tetmajer,³ and of the Bureau of Standards.⁴

For slate, the average specific gravity generally varies between 2.6 and 2.8.

Porosity and absorption. The porosity of a stone represents the maximum limit of absorption. The total amount of pore space may be calculated from the formula:

$$P = \frac{100}{t} (t - a)$$

in which t is the true specific gravity, a , the apparent specific gravity, and P the porosity expressed as percentage by volume. In this formula a represents the specific gravity as obtained by methods referred to above, whereas t represents the theoretical true specific gravity when there is no pore space in the rock. The value t may be obtained by immersing a known weight of the finely-crushed rock in a known volume of liquid and noting the increase in the total volume of liquid and solid.⁵

The factor of absorption is especially important in a structural material because, when exposed to conditions of moderate humidity, a porous rock may take on much moisture from the air or ground; this has the effect of seriously reducing its compressive strength, as well as of favoring spalling if frost ensues.

¹ Goldman, M. I., and Merwin, H. E., Color chart for the description of sedimentary rocks: National Research Council, Division of Geology and Geography, 1928.

² See however, Report of Com. D-16 on Slate, Am. Soc. Test. Mat., Proc., 33d Ann. Meeting, 1930.

³ Hirschwald, J., op. cit., pp. 107-109.

⁴ Kessler, D. W., and Sligh, W. H., Physical properties of the principal commercial limestones used for building construction in the United States: U. S. Bur. Standards Techn. Paper 349, pp. 515-517, 1927.

⁵ See especially Kessler, D. W., and Sligh, W. H., op. cit., pp. 516-517; Hirschwald, J., op. cit., pp. 109-110.

The amount of absorption depends in part upon the total porosity, in part on the size of the pores. If the pores are very fine they possess strong capillary power, whereas if they are coarse the stone will only take on a great deal of liquid if well submerged in it, and will also lose the liquid as rapidly as it disappears from the surrounding medium. Probably an equally important factor is time: a coarsely porous rock absorbs the surrounding liquid rapidly and also loses the liquid thus absorbed more quickly than a rock with fine pores. Hence the time during which a rock is exposed to the liquid should be carefully stated in all absorption tests.

Detailed methods for measuring absorption of water by rocks are given by Hirschwald, Dale, and others.¹ Most recently the American Society for Testing Materials has issued a tentative test for water absorption:²

Specimens should measure 6 x 6 inches on the cleavage surface and 1/4 inch thick. They may be hone-finished or merely roughly sawed and split. If the former, 6 specimens are used; if the latter, 9. The specimens are washed and dried at 110° to 120° C. for 24 hours, cooled 15 minutes to room temperature and weighed to the nearest 0.05 g.

After weighing, the specimens are immersed in water at 20° C. for 48 hours, then thoroughly wiped on all edges with a dry cloth and weighed at once.

The value of absorption is given by the formula:

$$\text{Per cent absorption} = \frac{(B-A) 100}{A},$$

in which A is the weight before and B that after immersion. The result reported should be the average of all specimens tested; individual values which differ by 25 per cent from the average of all results may be thrown out.

It will be observed that the method described, like most others, takes no account of the varying specific gravity of the rock tested. Thus a heavy rock, such as basalt, would appear to have relatively less pore space than a lighter rock, such as a sandstone, merely because of the differing weights of A in the formula given. To obviate this difficulty, it has been suggested that the *volume* of absorbed water may be divided by the *volume* of the specimen, the result thus expressing absorption in volume ratio;³ this is not generally done however, and since the specific gravity of most slates varies within relatively narrow limits, the differences introduced by this element, in comparing absorption values of various slates, are negligible.

Hirschwald cites results of tests on six different types of slates; when slowly immersed at atmospheric pressures these absorbed from 0.58 to 1.01% of their total weight of water.⁴ Kessler and Slight give average values of 0.3 to 2.0, using two weeks as the absorption period.⁵ All of these values are higher than those of Merriman, but the period of exposure for Merriman's tests was only 24 hours.⁶

¹ Hirschwald, J., op. cit., pp. 110-115; Dale, T. N., op. cit., pp. 177-178.

² Abridged from Am. Soc. Test. Mat., Tentative Standards for 1929, pp. 545-546, 1930.

³ Kessler, D. W., and Slight, W. H., op. cit., pp. 514-515.

⁴ Op. cit., p. 117.

⁵ Op. cit., p. 515.

⁶ Merriman, Mansfield, The strength and weathering qualities of roofing slates: Am. Soc. Civ. Eng., Trans., vol. XXVII, pp. 340-341, 1892.

Hardness. Hardness of materials is usually expressed in terms of resistance to an intruded point. The ordinary method of measuring is by means of one of the several different types of selerometers.¹ This method is now in general use in the United States. Merriman suggested abrading a piece of slate by means of a grindstone, but the suggestion has not found general acceptance. The use of a Deval abrasion machine is recommended by Notvest.²

Toughness. As applied to rock, toughness may be defined as the resistance offered to fracture under impact.³ The test is made by allowing a hammer which weighs 2 kg. to drop from increasing heights upon a spherical-headed plunger; the sphere impinges on the block of stone to be tested. The hammer falls 1 cm. the first time, 2 cm. the second time, and so forth. The height of fall at time of rupture measures the toughness of the rock.

Obviously the toughness of a given piece of slate would be greatly affected by the rock structure of the surface exposed to the blow: the cleavage surface is the most resistant.

Crushing strength. Although a very important quality in most stone, the crushing strength of slate does not seriously affect its use. The usual method of making the test is to cut cubes of a specified size and crush them in some type of compression machine. Both the transverse cross-section and the height of the block seriously affect the results; hence for comparative purposes it is necessary to use blocks of a constant size. Gilmore⁴ found this difficulty in his earlier work. Subsequently Bauschinger, on the basis of empirical experiments, concluded that the resistance to compression is best expressed by the formula:

$$K = (a + b \frac{\sqrt{f}}{h}) \frac{\sqrt{f}}{\frac{u}{4}}$$

in which K is the load in kg. per sq. cm., a and b are constants for the material tested, f is the cross-section of the cube tested in sq. cm., h is the height of the cube, and u is the circumference of the cross-section in cm.⁵ If the cube measures 1 cm. in each dimension the formula is simplified to

$$K = (a + b),$$

which gives the simple formula for crushing strength. Values may, of course, be expressed either in kilograms per square centimeter or in pounds per square inch.

Great extremes of temperature to which the rock has been subjected or a high moisture content both reduce the crushing strength of the rock. Also, slate possesses much greater crushing strength when pressure is applied in directions at right angles to the cleavage planes than when parallel to cleavage.⁶ In either case, however, since slate is not generally used to support great weight, the crushing strength is almost

¹ See Hirschwald, J., op. cit., pp. 83-88.

² Notvest, Robt., Slate for electrical uses, Structural Slate Co., Pen Argyl, Pa., 1924, p. 22.

³ Am. Soc. Test. Mat., Tentative standards for 1924, pp. 924-925, 1925.

⁴ Quoted in Merrill, G. P., Stones for building and decoration, John Wiley, New York, 1916, p. 475.

⁵ Quoted in Hirschwald, J., op. cit., pp. 60-61.

⁶ Merrill, G. P., op. cit., p. 506.

always far in excess of that required by any of the uses to which the slate is commonly put.

Transverse strength. The transverse strength is measured by the modulus of rupture. Earlier methods for obtaining this value are given by Dale.¹ The most recently standardized test is as follows:

Strips are cut to measure 12 inches long by 1½ inches wide parallel to the cleavage; they are rubbed down to a thickness of 1 inch, dried at 110° to 120° C. for 24 hours, and then their length, width, and thickness are measured in terms of inches to within 0.01 inches. Each specimen is supported on two knife-edges, 10 inches apart at centers, and is loaded by another knife-edge midway in the span. The load is increased at the rate of 100 pounds per minute and each 50 pound increment noted. Rupture is recorded at the nearest 5 pounds.

Calculations for Mf (the modulus of rupture) are based on the formula:

$$Mf = \frac{3wl}{2bd^2}$$

in which w is the breaking weight in pounds; l , the length of the span in inches; b , the width in inches; and d the thickness in inches. The tests should represent at least three experiments with the strips cut with their lengths parallel to the grain, and three with their lengths transverse to the grain. Results should be reported as averages for each direction. Should any single test vary by more than 25 per cent from the average of all like tests it may be omitted.²

Elasticity. This is one of the most important physical properties of slate. The use of blackboards and to a large extent of switchboards is seriously influenced by it, and the milling of slate is affected by its elasticity to a much greater degree than is commonly realized. But it is of chief importance in the splitting capacity of the rock, upon which most of its uses directly depend, and except for the remarkable elasticity of slate this quality of ready cleavage would be utilized with difficulty.

Merriman³, Shearer⁴, and others regard elasticity and toughness as identical. The more recent work of the American Society for Testing Materials, on the other hand, carefully distinguishes between the two and suggests two wholly different tests. The test for toughness has already been described (see page 113). That for the modulus of elasticity is as follows:⁵

The specimens are cut into strips measuring 12 x 4 x 5/8 inches, 3 having their long dimensions parallel to the grain and 3 at right angles to the grain, the two greater dimensions in both cases being in the plane of the cleavage. The specimens are then rubbed or honed down to thicknesses of about 3/4 inch each.

These slate strips are dried as in the test for transverse strength and then supported on two knife-edges, specifications for which are given; the knife-edges are 10" apart on centers. The load is applied by a third knife-edge at the center; it is increased at a rate of 100 pounds per minute, and every 50-pound increase is recorded. The deflection of the slate beam is read with a deflectometer capable of registering accurately deflections of 0.001 inches.

For computing, a straight line curve of any suitable scale is made. If it does not pass through the origin, a new line is drawn through the origin and parallel to the first line to give the "corrected" curve. The value of E , the modulus of elasticity, is now obtained by using any convenient point on the corrected curve and applying the formula:

$$E = \frac{Wl^3}{4\Delta bd^3}$$

in which W = the load at the selected point, Δ is the corresponding deformation

¹ Dale, T. N., op. cit., p. 175-176.

² Condensed from Am. Soc. Test. Mat., Tentative Standards for 1929, pp. 547-549, 1930.

³ Merriman, Mansfield, The strength and weathering qualities of roofing slates: Am. Soc. Civ. Eng., Trans., vol. XXVII, p. 339, 1892.

⁴ Shearer, H. K., The slate deposits of Georgia: Ga. Geol. Survey Bull. 34, p. 31, 1918.

⁵ Quoted in abridged form from Am. Soc. Test. Mat., Tentative standards for 1929, pp. 549-550, 1930.

as obtained from the curve, l is the length of the span in inches, and b and d are respectively the width and thickness of the test specimen in inches. The average values of the three specimens cut parallel and at right angles to grain shall be reported as the value of E parallel and at right angles to the grain respectively. Values varying from the general average by 25% may be thrown out.

Electrical Resistance. Tests for electrical resistance are also sometimes described as conductance, insulation, or leakage tests. Electrical resistance is a quality of interest only in slate to be used for electrical insulation. Various ways of testing electrical resistance have been devised.¹

The most widely accepted tests are the two prescribed by the American Society for Testing Materials; they are given below.²

The first method is as follows:

Apparatus:

Transformer: Standard 10,000 volt portable testing transformer of 5 K. V. A. rating.

Ammeter: With full scale reading of 5 amperes.

Current Source: 115 to 125 volt alternating current with frequency of 25 to 60 cycles and approximately sine wave form.

Electrodes: Of 4/0 copper wire with rounded ends, adequately insulated.

Specimens:

Size may be variable; all edges should be sand-rubbed or honed.

Procedure:

Connect the ammeter in series with the low-voltage side of the testing transformer and note the exciting current.

Connect the high-voltage side for 5,000 volts.

Then note the increase in current (as recorded by the ammeter) above the no-load exciting current of the transformer.

The above procedure should be carried out:

a.—On the edges and surfaces, with the electrodes 2 inches apart.

b.—While the slate stands on edge on a sheet of metal, one electrode should be placed in contact with the metal while the other is moved all over the slate surface.

c.—The slate should be placed firmly on the metal so as to give a good contact and one electrode placed on the metal; then the surface should be thoroughly gone over with the other electrode.

The second method calls for more complex equipment:

Apparatus:

Transformer: A 30 : 1 potential transformer of 200 K. V. A. capacity.

Voltmeters: Two 150-volt alternating current voltmeters (V_1 and V_2).

Current Source: 115-125 volt A. C. source, with frequency of 25-60 cycles and preferably a sine wave form.

Electrodes: Padded, 4" square, so arranged as to clamp down and make intimate contact directly opposite each other on the sides of the slate block; provided with insulated handles.

Rheostat: Variable (R_1); for controlling voltage across voltmeter V_1 .

Resistance: Fixed (R_2); 14 ohms.

Specimens: Size variable; finish smooth (sand rubbed or honed).

Procedure: The apparatus is set up as indicated in Figure 27.

The electrodes are set and clamped directly opposite each other, so as to make close contact with the slate. Reading 110 volts on V_1 , the voltage reading on V_2 indicates the insulation value of the slate. As soon as V_2 is read, the electrodes may be moved.

Calibration must be accurately carried out.

The latter method can be readily used by the unskilled worker.

¹ Purdue, A. H., The slate of Arkansas: U. S. Geol. Survey Bull. 430, pp. 329-330, 1910; Bristol, W. A., High tension testing of Vermont slate and marble: Rept. of Vermont State Geologist for 1911-1912, pp. 196-219, 1912; Harvey, Dean, and Keyes, J. J., Electrical slate: Am. Soc. Test. Mat., Proc., vol. 23, II, pp. 535-544, 1923; Spurek, R. M., Insulation tests of slate for electrical use: Am. Soc. Test. Mat. Proc., vol. 23, II, pp. 545-554, 1923; Notvest, Robt., in Slate for electrical purposes, Structural Slate Co., Pen Argyl, Pa., 1923, pp. 33-34.

² Abstract from Am. Soc. Test. Mat., Tentative standards for 1929, pp. 551-553, 1930.

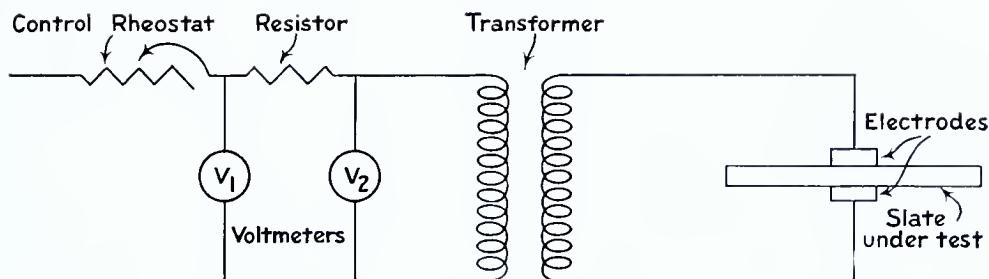


Fig. 27. A. S. T. M. apparatus for testing electrical resistance. For explanation, see text.

An apparatus especially adapted to field tests has been devised by Notvest¹ and is in general use in the United States.

Resistance to corrosion. Structural slate that is used in toilets or laundry tubs or where highly acid or alkaline vapors or solutions may come in contact with it, and roofing slate in certain types of factories—such as smelters, acid plants, fertilizer works, and the like—may, like other structural materials, be subject to corrosion. Although slate is very resistant to both acids and alkalies, this type of attack, if extended over sufficiently long periods, may ultimately produce color changes (see pages 19-22) or might conceivably result in some disintegration. Fresenius, Merriman, Notvest, and Lancaster and Behre² have all devised methods for testing the resistance of slate to such corrosive agents. These methods are all accelerated tests, which make up for the time available for the process in nature by increasing greatly the strength of the reagents. The principal corrosive agents used are sulphurous, sulphuric, nitric, hydrochloric, acetic, and sulphuric-hydrochloric (mixed) acids and sodium and ammonium hydroxides in solutions of varying concentration. No definite standards have yet been devised. Any really useful tests must face two different effects,—color changes and severe textural disintegration.

TECHNOLOGY OF SLATE

The technology of slate has been thoroughly discussed by Bowles³. Since that publication several shorter papers have appeared, however. It is the purpose of what follows to bring together the information contained in the publication mentioned and that of more recent date, in such a form that it shall be conveniently available for users of this bulletin. For technical details, the reader is referred to the special works mentioned in the footnotes.

In general, slate technology does not vary greatly from place to place. For this reason no special mention will ordinarily be made of the methods used in individual districts.

¹ Slate for electrical uses, publ. by the Structural Slate Company, Pen Argyll, Pa., 1924, pp. 33-34.

² Fresenius, R., Ueber die Pruefung der Daechschiefer auf den Grad ihrer Verwitterbarkeit: Zeitschr. anal. Chemie, vol. VII, pp. 72-78, 1868; Merriman, Mansfield, The strength and weathering qualities of roofing slates: Am. Soc. Civ. Eng., Trans., vol. XXVII, pp. 341-342, 1892; Notvest, Robt., The resistivity of slate against acids and alkalies, privately published, Cleveland, 1925; Lancaster, C. L., and Behre, C. H., Jr., Chemical experiments on acid and alkali resistance of slates; Am. Soc. Test. Mat., Proc., Report of Sub-Com. on Slate, 1930.

³ Bowles, Oliver, The technology of slate: U. S. Bur. Mines Bull. 218, pp. 23-123, 1922.



A. Columbia Bangor quarry at Bangor; waste from stripping being dumped into old opening.



B. Stripping glacial overburden with steam shovel; east end of Columbia Bangor quarry.



A. A typical slate quarry, showing several levels or "pieces;" the smooth edges were cut with a wire saw. Photograph by Bliss, Easton, Pa.



B. Wall of a slate quarry; to show contrast between blasted (rough) and channeled (smooth) surfaces.

QUARRY PRACTICE

Form of quarries. In all Pennsylvania districts it is customary to follow a simple quarry plan. The opening is approximately rectangular or rhomboidal, two sides being parallel to the cleavage strike and two parallel to the grain. The quarrymen speak of the edges parallel to the grain as the "sides" of the quarry, and the other two edges are called "back" and "front." On account of the general parallelism in the strikes of bedding and cleavage, the "back" and "front" are commonly parallel also to the bedding strike. In all of the Pennsylvania districts the "sides" trend northwest, with "back" and "front" extending northeast. Many quarries represent fusion of several individual operations and therefore depart notably from the ideal pattern.

Depth varies greatly. In quarries where the beds are flat lying ("run fast," as the quarrymen put it) the opening is likely to be large but shallow; where the beds are steeply dipping, it is more commonly small and deep. Thus at Pen Argyl, where the beds approach the vertical, several quarries are well over 500 feet deep. At Bangor, where the folding is around horizontal axes and the bedding more nearly flat, the openings have a larger surface area and do not generally exceed 250 feet in depth. At Slatington the depths are intermediate. In the Peach Bottom district, since bedding was not a controlling factor, the depth has been controlled not as much by geologic as by working factors, such as safety of walls and drainage facility. It should be obvious that hoisting time increases with depth and that shallowness has consequent advantages which may overbalance other disadvantages.

The quarrymen designate the several levels or benches of quarries as "pieces."

Mining. In several places in the Pennsylvania slate districts underground mining has met with success. At Slatington two true mines were operating in 1927 and many other openings had at their bottoms short tunnel-like tongues of very large cross-section, suggesting the stopes of a metal mine. Generally an old quarry opening serves as the shaft, but at the Cambridge mine near Slatington, rock shafts, about 40 feet square, were put down to reach the desired bed. These methods have the advantages that operations are not affected by ice in winter nor by inclement weather, and cribbing and extensive top stripping are avoided. The handling of much waste is also obviated. On the other hand ventilation introduces some difficulties and steam and smoke combine to confuse the sight unless a draft is provided in some way.

In the Peach Bottom district mining has not only been carried on locally, but in at least two cases long tunnels were driven from topographic depressions to tap the slate at depth.

Stripping. As the quarry is extended in any direction horizontally the overburden is removed either by hand, or, more commonly, by steam shovel. Hydraulic stripping has been suggested but has not found favor, probably because the lower part of the material to be stripped is really solid rock and possibly also because of the proximity of other quarries subject to flooding. Not infrequently a track is laid from the shovel to some place farther from the quarry operations, and cable-hauled trams are used to carry away the stripped glacial debris or waste slate. In many places the waste is thrown into a part of the

PLATE 16.



A. Broaching bar with mounted drill; New Peerless (Bangor Vein) quarry.



B. Wire saw in operation; the wire is seen entering the cut half-way up the nearest standard. Photograph by Bliss, Easton, Pa.

quarry which has been abandoned. This is wise only if there is no doubt whatever that such abandonment is to be permanent.

Drilling. Drilling is now done almost wholly by machine drill, compressed air being the power employed. Although it expedites quarrying, drilling is likely to shatter the slate somewhat, so that it is customary to drill into the less valuable beds.

Blasting. In the past, blasting has been resorted to more than now. It is finding less favor as time goes on. Dynamite and hand firing are most usual. Blasting as a general practice has been severely condemned by Bowles because it shatters the slate and breaks it into splintered fragments. The contrast between blasted and channeled walls is shown in Plate 15, B.

Channeling. Channeling machines are being substituted for cruder methods in cutting the slate away from the sides of the quarry. The track channeler is now in general use. It shatters the slate for some distance from the channel cut, but is otherwise generally satisfactory.

The use of the channeler in a given region is affected by the cleavage dip in the slate, as pointed out on page 30. Its success depends also upon the resilience or toughness of the rock. Quarrymen assert that the slate in the Bangor beds is fractured over a much smaller area adjacent to the channeler than in the Pen Argyl beds, and that in the latter the slate of the Diamond "run" is more heavily shattered than that in the Albion "run."

Drilling and broaching. In the last few years, Bowles has advocated a return to the older method of drilling and broaching, especially in those quarries where the slate is very brittle or "tender," and where the loss through shattering consequent upon the use of channeling machines is excessive¹. For this purpose the drill is mounted on "quarry bars," two heavy bars, one above the other, on a wooden frame. The drill mounting holds the drill exactly vertical, and as it may be slid back and forth on the bars, a line of holes 8 to 10 feet in length may be drilled from one position of the bars. The holes are drilled 8 to 10 feet deep and as close together as can be conveniently accomplished without a tendency for the drill to run into the adjacent hole. Cores $\frac{3}{4}$ to $2\frac{3}{4}$ inches wide, depending upon the ease with which the slate is broken, are usually left between the holes, but the cores are wider at the bottom as the drill loses gage with depth. As each hole is completed a wooden plug is driven to keep it free of cuttings. The cores are cut out in a subsequent operation with a broaching tool. This method appears well adapted to the Pen Argyl beds, especially to those above the Albion "run"; in the tough slate of the Bangor beds it seems to be unnecessary. At Slatington, too, it has met with limited success (see Plate 16, A).

Use of the wire saw. In 1926, through the Bureau of Mines, the wire saw was introduced into American slate quarries², primarily in the hope of reducing the amount of waste caused by shattering the slate through blasting, channeling or drilling. The apparatus consists of a 3-strand steel cable, varying between $\frac{3}{16}$ and $\frac{1}{4}$ of an inch in

¹ Bowles, Oliver, Technical progress in slate mining: Eng. Min. Jour.-Press, vol. 117, pp. 606-607, 1924.

² Bowles, Oliver, The wire saw in slate quarrying: U. S. Bur. Mines Techn. Paper 469, 31 pp., 1930.

diameter and traveling as an endless belt over the slate, with sand as an abrasive. The wire passes over an electrically run drive pulley and thence over sheaves mounted on standards. The latter are sunk in holes cut or drilled for the purpose, so that the wire is brought against the slate. The sand abrasive mixed with water is fed upon the wire where it enters the cut. (See Plates 15 A and 16 B).

For the wire saw it is claimed that the amount of slate broken in the actual channeler cut is nine times as great as that abraded by the saw; this figure would be further increased if allowance were made for the shattering of the slate that borders the channel cut. It is stated also that in a given time the wire saw will cut four or five times as much as a channeling machine. In one case, to give concrete data, the cost per square foot of operating a wire saw was only about a third as high as for a channeler.¹ On the other hand it is maintained that the channeling machine will, in the best regulated quarries, still be found necessary for short cuts².

Removing blocks. Although the methods used in removing slate from the floor of the quarry vary greatly according to the structure of the slate and the predilection of the operators, the general plan may be outlined. Operations first lay bare the cleavage surface that forms the floor or steeply-sloping "back" of the opening. In Pennsylvania quarries the floor generally slopes southward at angles not exceeding 25° ; rarely it is horizontal. If the cleavage dips steeply, as in the Peach Bottom district, a floor must be developed inclined to the cleavage, if possible along joints.

Slate is now removed from one corner or part of the quarry to furnish a more or less vertical face, the "key" face, by means of which the rest of the slate making up the floor can be attacked. A channeling machine or drilling and broaching device is now used, or a series of holes is drilled and a charge fired so as to break the slate parallel with the grain direction and along the side wall of the quarry. A channel, broach, or wire saw cut is then made approximately at right angles to this line of fracture. Another fracture is induced along the grain, but far enough away from the first to give the desired width to the slab. There is now a well-defined rhombic block, three sides of which are bounded by the fractures described above, and the fourth by the vertical "key" face.

Next, a series of holes is drilled into the "key" face in such a way that all holes lie in the same cleavage plane. A light charge of powder is exploded in these holes to free the surface slate from that below the holes. A more or less rhomboid block is thus freed. This block is now pried up by several men, who work in unison, using crowbars as levers. It is then ready for removal from the quarry.

Occasionally an unusually regular system of joints can be utilized so as to obviate the channeling at right angles to the grain. In that case the edges of the block to be removed are bounded by two joints on opposite sides (if conditions are ideal), by two fractures induced along the grain on the remaining sides, and by the cleavage plane below.

Many variations in method are substituted where structural relations of bedding, cleavage, or jointing are suitable.

¹ Bowles, Oliver, op. cit., pp. 24-27, pp. 29-30.

² Focht, Doster, Discussion of Behre, C. H. Jr., Geologic factors in the development of the eastern Pennsylvania slate belt: Am. Inst. Min. Met. Eng., Trans., vol. 76 p. 411, 1928.



A. Typical hoisting boxes used in Pennsylvania quarries; note cribbing to protect opening.



B. Trimming and splitting slate in the roofing slate shanty; the chain that moves the trimming tool is attached to the spring pole above the window. Photographs by Bliss, Easton, Pa.

By further breaking along the grain, cleavage or joint surfaces, the large block of slate may, if necessary, be still more reduced in size until it can be conveniently hoisted out of the quarry.

Hoisting. In all of the Pennsylvania slate districts the quarries are equipped with steel or wooden masts, which support steel cables that are thrown across the mouth of the opening and are anchored by heavy guy-ropes on the side opposite the landing. The main cables measure 1.5 to 2.5 inches in diameter, while the draw cables are from a quarter to three-quarters of an inch thick, the cableways being designed to carry from three to five tons, according to Bowles. Carriers are used on the cables and from these a chain is suspended which is directly attached to the large blocks of slate, or, when men or waste pieces are to be hauled, is fastened to a flat box.

"Gin poles" (rotating derrick booms) have been used by only one company. They have the disadvantage of a smaller working radius but are said to save time in hoisting.

Hoisting is done by drums mounted in covered engine houses some distance back from the brink of the quarry. Instructions for hoisting are given by the men in the hole, who call or motion to the "signal boy", generally a boy or young man stationed in a small shanty that overhangs the quarry. The "signal boy" then directs the engineer, either by voice or, more commonly, by a system of bell signals.

Great care is taken in hoisting, and close cooperation between the men in the hole, the "signal boy", and the hoist engineer is required.

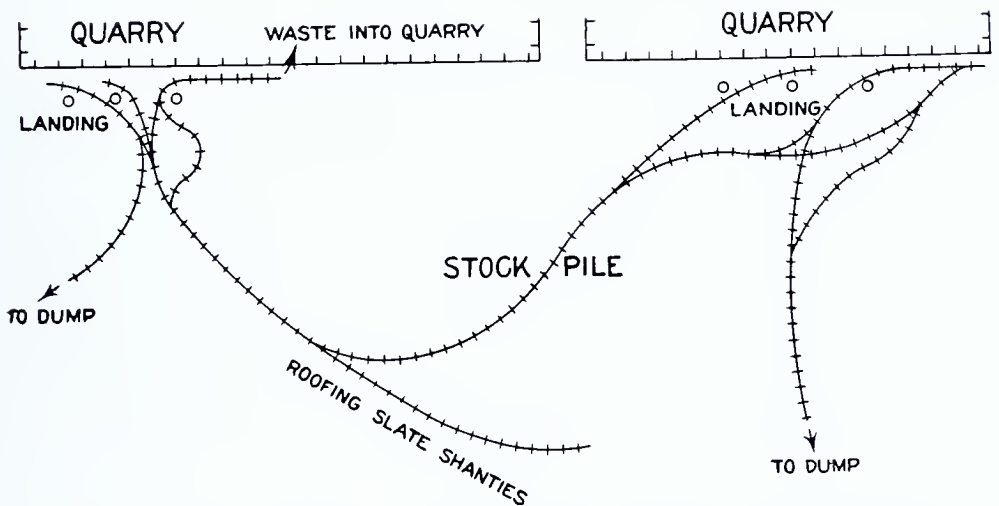


Fig. 28. Plan of tracks of Chapman Slate Company, Lehigh-Northampton district. Access by rail is afforded to shanties, waste dumps, and quarries.

Transportation from the quarry landing. Waste slate removed from the quarry is generally placed on hand cars and hauled to the dump.

Large blocks are marked before removal from the pit, to indicate whether they are to be thrown away, or used for millstock, roofing, or blackboards. Those to be used are loaded on four-wheeled truck trams and pushed by hand or hauled by mules either to the mills, for finishing into structural, electric, or blackboard material or to the "shanties", in which roofing slate is made.

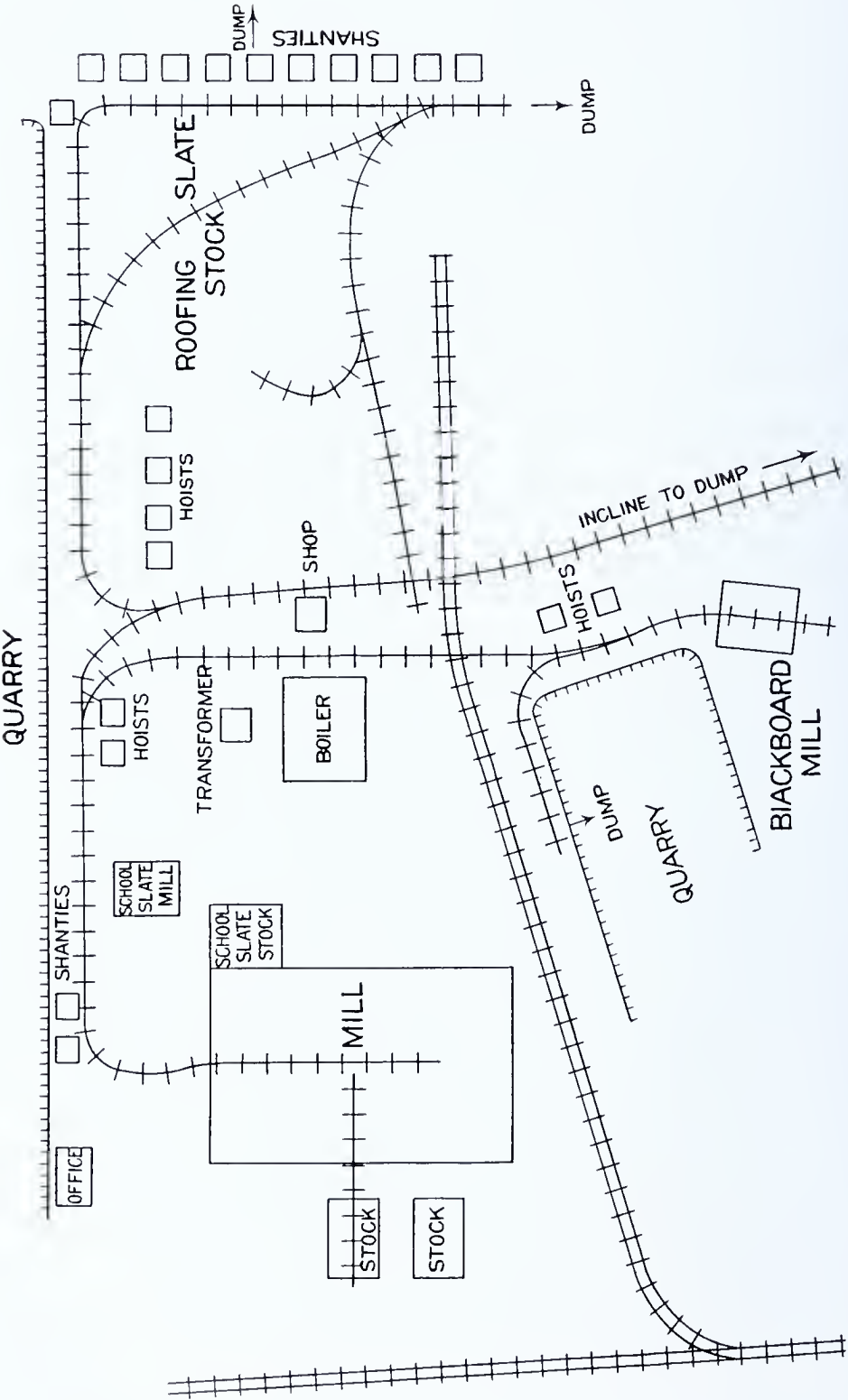


Fig. 29. Plan of mill, dumps, and quarries of the North Bangor Slate Company, Bangor. Note that slate can be shifted by rail between all parts of the operations, thus saving hand labor.

SHANTY PRACTICE

Shanty design. Until recently it was customary to carry on the splitting and trimming of roofing slate in small wooden buildings roughly 10 by 10 feet in plan. These are the "shanties". They were placed some distance from the "factory", where structural slate was made, so as to distribute the waste from the two processes. Being simply constructed, they could be moved or raised as desired.

In plants of more modern design the splitting and trimming are done in one large building, through which a hand or horse ear is drawn to haul away the waste slate. These mills are described below under "Modernized procedure".

Reduction in size. Blocks sent from the mill or directly from the landing to the roofing slate shanties must be reduced to dimensions adapted to ready handling. The saw used for this purpose is generally 36 inches or more in diameter, and is about $\frac{3}{8}$ inch thick; the teeth are fixed in one piece with the blade. The saw turns slowly around a horizontal axis, making between five and ten revolutions per minute. While it rotates the iron table on which the slate rests moves forward at a slow rate. As the table is slotted and the saw is directed to follow the slot, the slate is gradually forced against the teeth of the saw, which cuts it, according to Bowles, at the rate of three to twenty inches per minute. To prevent the slate block from being pushed back on the table as the saw advances against it, plugs are driven around the piece into the holes of the grating that forms the table. If necessary, the block is thinned after sawing by splitting it with wedges set parallel with the cleavage.

One quarry has found the diamond saw better than any other for trimming roofing slate before splitting. It has also been suggested that a saw tipped with the newly developed alloy, tungsten carbide, might prove satisfactory and experiments seem to show as much¹. For both of these saws, the speed is believed to more than balance the greater cost, but the final results of tests are not yet available.

In some quarries, notably in the "hard" belt of Northampton County, one or two saws are set up near the shanties to cut up only such slate as is intended for roofing. In quarries where mills are operated, however, the smaller pieces cut from the large blocks that were destined for structural purposes are also utilized and these of course, require no sawing but are sent directly to the shanty.

Splitting. When the slate has been reduced to pieces about 1.5x2 feet in area and 5 inches or less in thickness, it is carried to the shanties. Here the splitters swab the blocks with water. A thin, wide-bladed, and very flexible chisel is then worked into the slate along cleavage cracks by gentle tapping with a mallet. When the chisel is finally well inserted another is commonly entered in like manner, prying apart the same two cleavage surfaces. Gentle tapping and deeper forcing of the chisels finally induces the slate to part along the desired plane.

Attempts have been made to introduce mechanical splitters, but the machine has not found favor.

¹ Mimeographed reports of Committee D-16 on Slate, Am. Soc. Test. Mat., Jan. 22, 1930, p. 4, and Jan. 19, 1931, p. 6.

The usual thickness to which roofing slate is split is $3/16$ of an inch. Standard specifications, however, provide for the following additional sizes: $1/4$, $3/8$, $1/2$, $3/4$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, and 2 inches¹.

Trimming. After the rock is split to the thickness of roofing slate, it is trimmed under a heavy steel blade which is fixed at one end and is operated by a treadle. The blade is made to swing by a spring pole, placed outside the shanty, or by a coil spring. This instrument cuts the larger pieces of thinly split slate into the sizes desired for roofing. This is clearly an antiquated device. A more modernized design is a power-driven machine, which obviates the tiring foot treadle.

In general a piece of slate is cut out to the largest size possible consonant with the standard roofing sizes. A set of metal plates attached to the trimming machine is so arranged as to permit the rapid gauging of the dimensions to which the slate piece is best adapted. It is said that the treadle must be worked more slowly for more brittle and softer slate.

Punching. On demand some producers still punch the slate with nail holes. This is done with a machine operated by a treadle. Opinions differ among operators as to the desirability of punching slate before shipment. Some assert that the loss suffered by the operators is appreciable. Others maintain that the service is better if punching is done at the quarry because the full quantity of slate ordered is then available to the consumer, no losses being sustained by him after receipt of the shipment; this, they believe, begets better feeling between producer and consumer and more than balances the financial loss through occasional breakage in punching.

A higher price is charged for punched slate. Punchers are paid on a piece basis.

Storage. Roofing slate is generally stored out of doors. When exposed to the weather the slates generally become a shade lighter in color and producers prefer that the preliminary exposure or "seasoning" should take place at once, prior to shipment. In the Pen Argyl region the practice of indoor storage is followed. Portable storage racks are in use locally, but more generally the finished slates are stacked on edge in "blocks", a course of lumber laid upon them, and then another "block" stacked upon the first.

Waste disposal. The chips from the shanties are commonly thrown from a chute placed conveniently near the trimming machine. A huge pile of waste gradually accumulates, necessitating periodic moving or raising of the shanties. This accumulated waste is a striking feature in the district. For a further discussion the reader is referred to the section under "Waste".

Modernized procedure. Recently separate shanties have been done away with by the more up-to-date companies, in favor of a single building; typical plans are given in Figures 30 and 31. Heavy blocks are handled with overhead traveling cranes. The trimming machines are power driven. The finished slates are piled on wheeled, portable racks, which are hauled to storage. Waste falls through chutes to a

¹ Roofing slate: U. S. Bur. Standards Simplified Practice Recommendation R 14-28, p. 1, 1928.

PLATE 18.



A Typical slate mill building, with roofing slate stock pile,
Cambridge Slate Company, Slatington.



B. Dump and twenty roofing slate shanties of Chapman Slate Com-
pany, Chapman, in Lehigh-Northampton district.

depressed track over which it is trammed to the dump, or it is fed by the chutes directly upon a continuous belt conveyor which carries it to the dump. These improvements are said to have increased production per man by as much as 200 per cent or more. In 1927, seven such roofing slate mills were in operation in Pennsylvania.

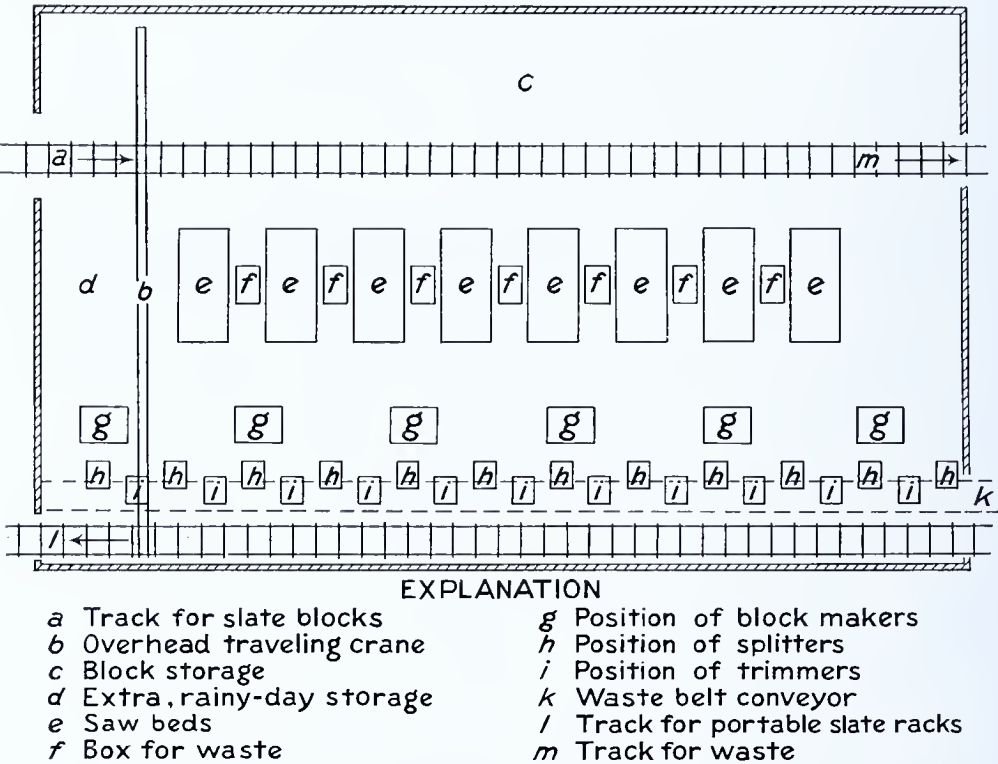


Fig. 30. Plan of Jackson-Bangor Slate Company roofing mill (after Bowles).

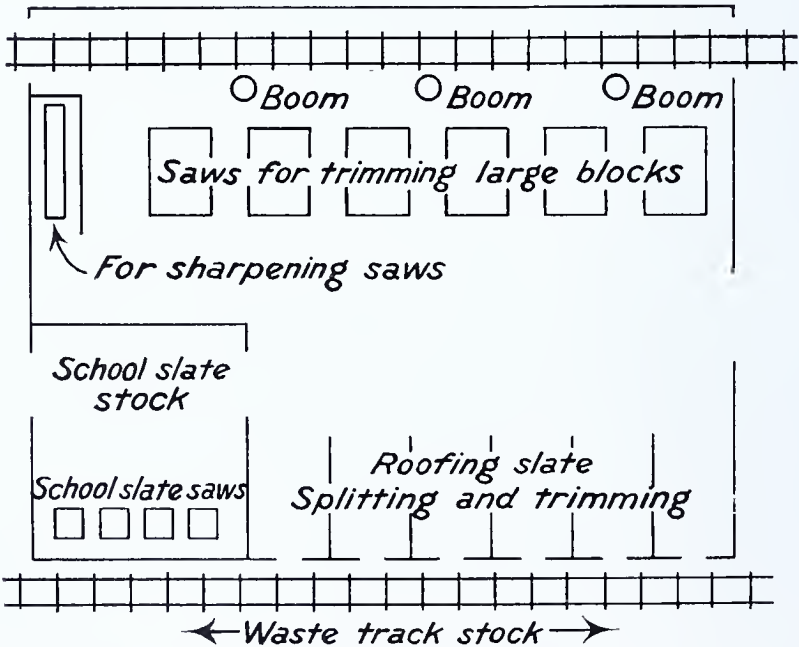


Figure 31. Plan of combination roofing and school slate mill of the Blue Ridge Slate Co., Slatington.

MILL PRACTICE

Comparison of milling methods. Mill practice varies slightly in the different districts. The two mills in the Peach Bottom district are south of the Maryland state line, but are representative of mill practice in that district. They are both simple in plan. Here, as also in the "hard" belt of the Lehigh-Northampton district, the only products besides roofing slate are grave vaults, fence posts, and rough slabs of various sorts. No elaborate mill machinery is necessary and the mill practice consists of sawing the slate into specified sizes, and then splitting to the desired thickness. The saws and chisels are similar to those employed for roofing slate. Planers are not commonly used and there are no rubbing beds.

In the Slatington, Bangor, Pen Argyl and related regions of the Lehigh-Northampton district, much structural slate of various types and sizes is produced and the process is far more elaborate. A brief description follows.

Sorting. Either in the quarry or on entering the mill, the slate blocks are graded, so that it is known whether they are intended for blackboards, structural slate, or electrical slate. In sorting, slate is designated as "clear stock" (consisting of only light gray or greenish gray slate, free from carbonaceous or sandy bands or "ribbons") and "ribbed stock" (in which there are differing beds in the block). Unusually thick beds of clear stock are set aside for blackboards. Pieces from certain beds which, through test or use, are known to yield good electrical material are saved for switchboards and insulation. Exceptionally dark, uniformly colored blocks are sent to the school slate factories but they are obtained from only a few well known beds.

Mill building and plan. Slate machinery is generally housed in a wooden shed, the mill or factory, which is longer than wide. An aisle is left open down the middle of the building and parallel with the length. In many mills tracks are laid in the aisle, and a small hand car utilized to transport the rough slate blocks or finished products.

The various pieces of machinery are arranged on either side of the middle aisle, in such a way as to facilitate as direct transportation from machine to machine as possible. The mill plans vary with the machinery used, the kinds of slate products made, and the views of the operators as to the best arrangement of the machines. Typical mill plans are presented in Figures 32 and 33. Bowles has discussed the matter of mill planning in much detail¹.

Power. Steam, gasoline, and electricity are all utilized for power in the slate districts. Steam power and electricity vie with each other for use in driving mill machinery and air compressors. Steam is generally used for hoisting. Gasoline is preferred for pumps and quarry machinery.

Electricity is furnished by public power companies. Transformers are a necessary part of the equipment.

Anthracite is the usual fuel. The boiler house is a separate building placed, as a rule, some distance from the mill.

In the mill the machinery is generally linked to one or two shafts which parallel the length of the building. Generally one of these is a

¹ Bowles, Oliver, op. cit., pp. 77-80, 1922.

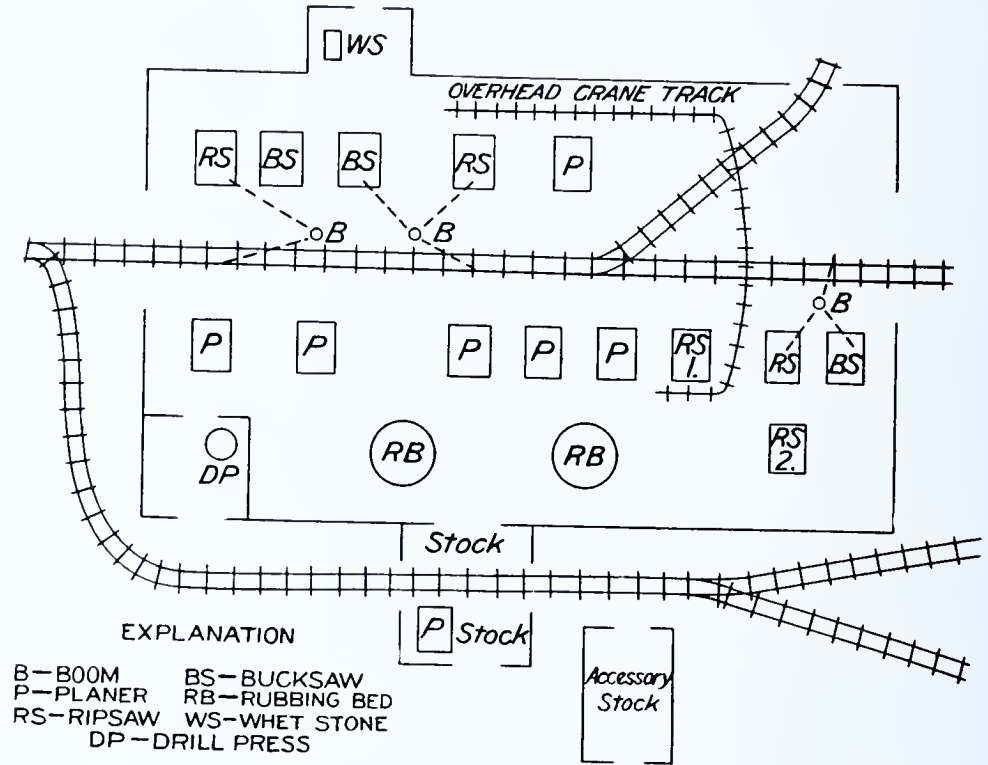


Fig. 32. Plan of mill of Consolidated No. 1-Star quarry at East Bangor; Lehigh-Northampton district.

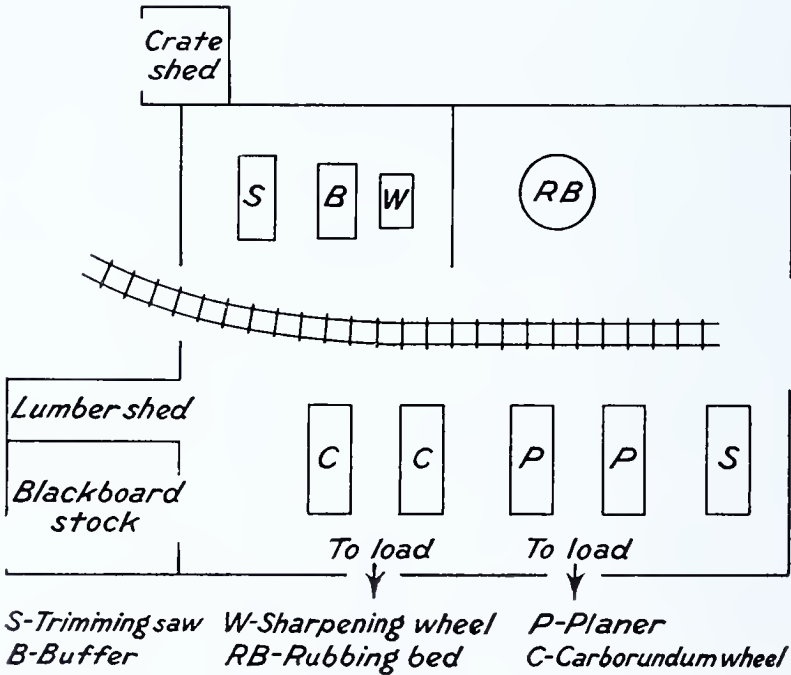


Fig. 33. Plan of small mill of Manhattan Slate Co., at Slatedale, which makes blackboards and electrical slate.

drive shaft and is belted to the other. In some of the more modern mills individual saws are equipped with their own motor-drive units.

Mill transportation. Four methods of handling raw and finished slate in the mill are utilized. These are, by boom, hand car, horse-power, and crane.

Many slate mills are equipped with a block and tackle attached to a rotating boom. Such an appliance is used outside the mill shed for moving blocks from the hand car to the saw tables, or within the building to shift pieces from one machine to another, the length of the horizontal arm of the boom being the measure of its working radius. In some mills the block and tackle can be moved along the length of the horizontal arm. In one mill a chain and grapple are mounted on an S-shaped track; this appliance is used for moving slate from saw table to planer.

Much transportation is effected by hand-pushed or horse-drawn cars, moving on a track which is laid along the middle aisle of the mill.

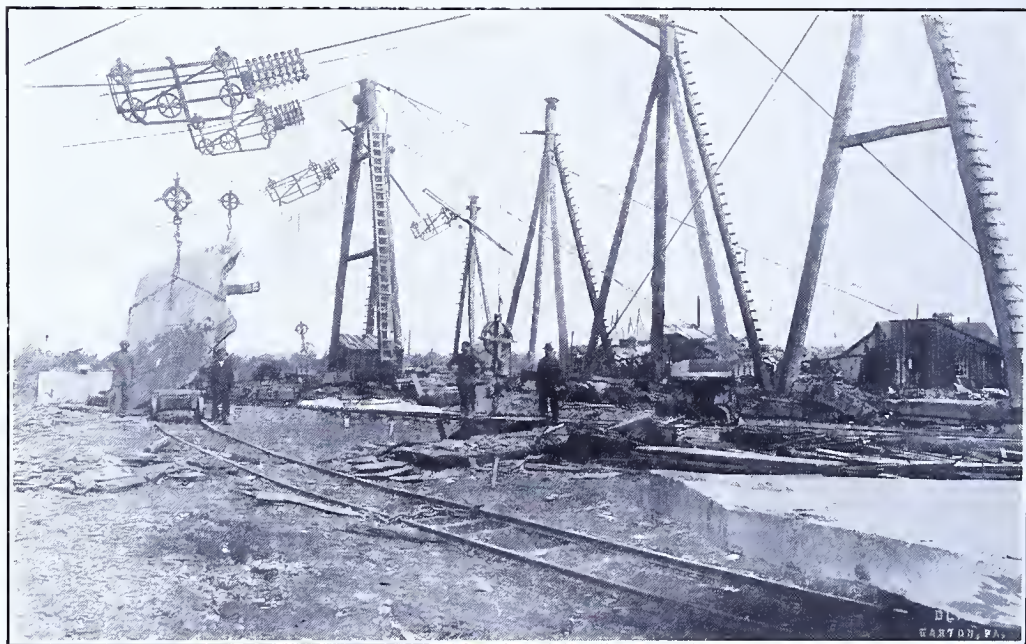
In four mills, overhead cranes, traveling on tracks attached to the roof, are installed. The five-ton Shepard crane appears to find most favor. The initial expense is a deterrent, but the crane certainly expedites the handling of waste and of larger blocks and so probably pays for itself in a short time.

Reduction in size. This process is similar to that already described in the case of shanty operations. Two sizes of saws are commonly used, one measuring up to 4 feet in diameter ("buck-saw") for the preliminary reduction of the rough blocks and another ("rip-saw") generally having a diameter of about 2 feet, for removing irregular edges or for cutting partly finished or thinner slabs. In some mills a large saw of the former type is mounted outside the mill shed. Within the shed the larger saws are generally placed near the entry, the smaller ones being closer to the planers and other machinery.

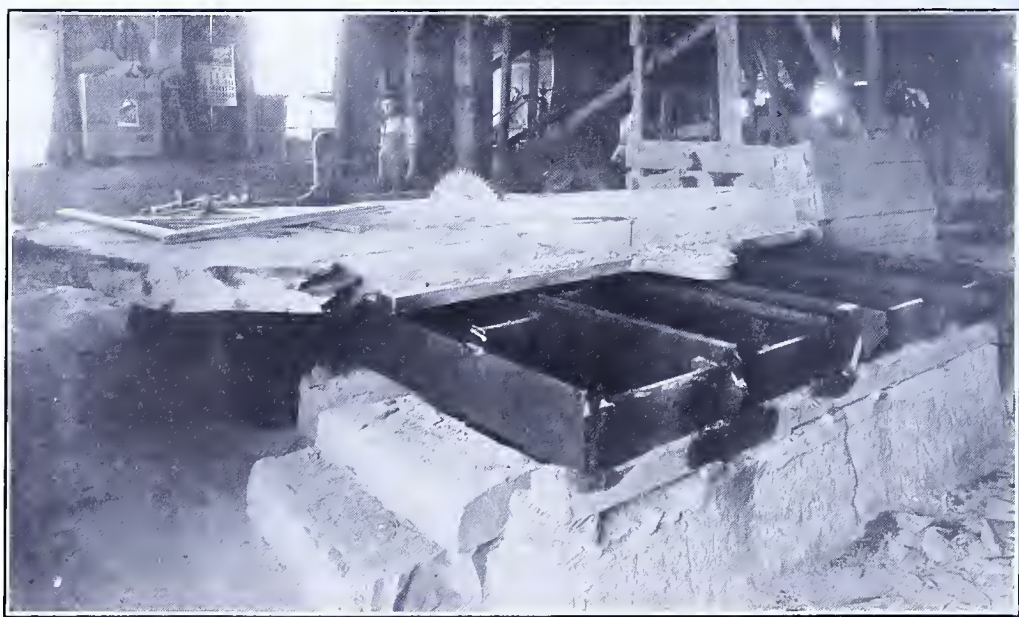
For recent advances in sawing technology, the reader is referred to the section on "Reduction in Size" on page 91.

Planing. The slate is next planed to a smooth surface. For this purpose the block is placed on a bed which travels back and forth as does a sawing table. The motion carries the slate under a blade which is set at a very low angle to the horizontal. Since the blade is not as wide as the bed on which the slate rests, and hence also generally not as wide as most slate slabs, it must be moved laterally from time to time to bring it in contact with the entire surface. Further, the blade is mounted in a geared rack, so that it may be progressively lowered to cut the slate into thinner slabs. Needless to say, such machines require skilled operators, as it is desired to make the surface absolutely plane.

Sand polishing. For much structural material the planed surface is sufficiently even, but in many cases, notably in the manufacture of blackboards, a yet smoother finish is desired. For this purpose, as well as for perfecting the edges of other pieces of which the large surfaces do not require a polish, a rubbing bed of circular plan is used. It consists of a disk of iron, 12 feet in diameter, rotating around a vertical axis. Sand is placed upon this as an abrasive and a stream of water is directed upon it. Downward pressure is exerted by weights placed upon the slate as it lies upon the rubbing bed.



A. Arrival of block of slate on landing.



B. Sawing slate on mechanical sawing table. Photographs by Bliss, Easton, Pa.

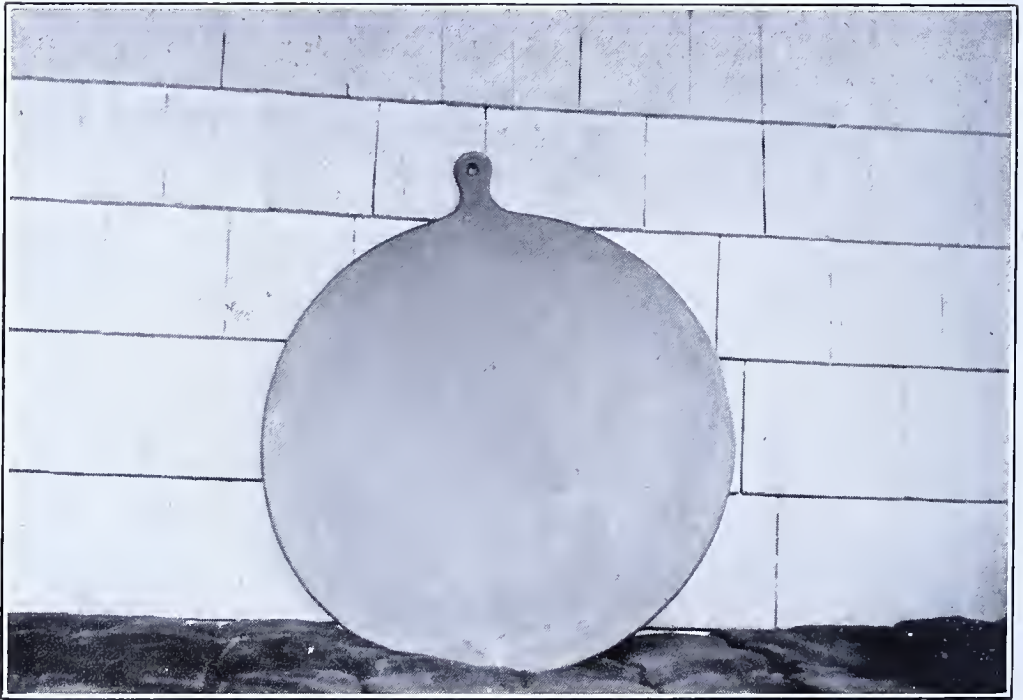
PLATE 20.



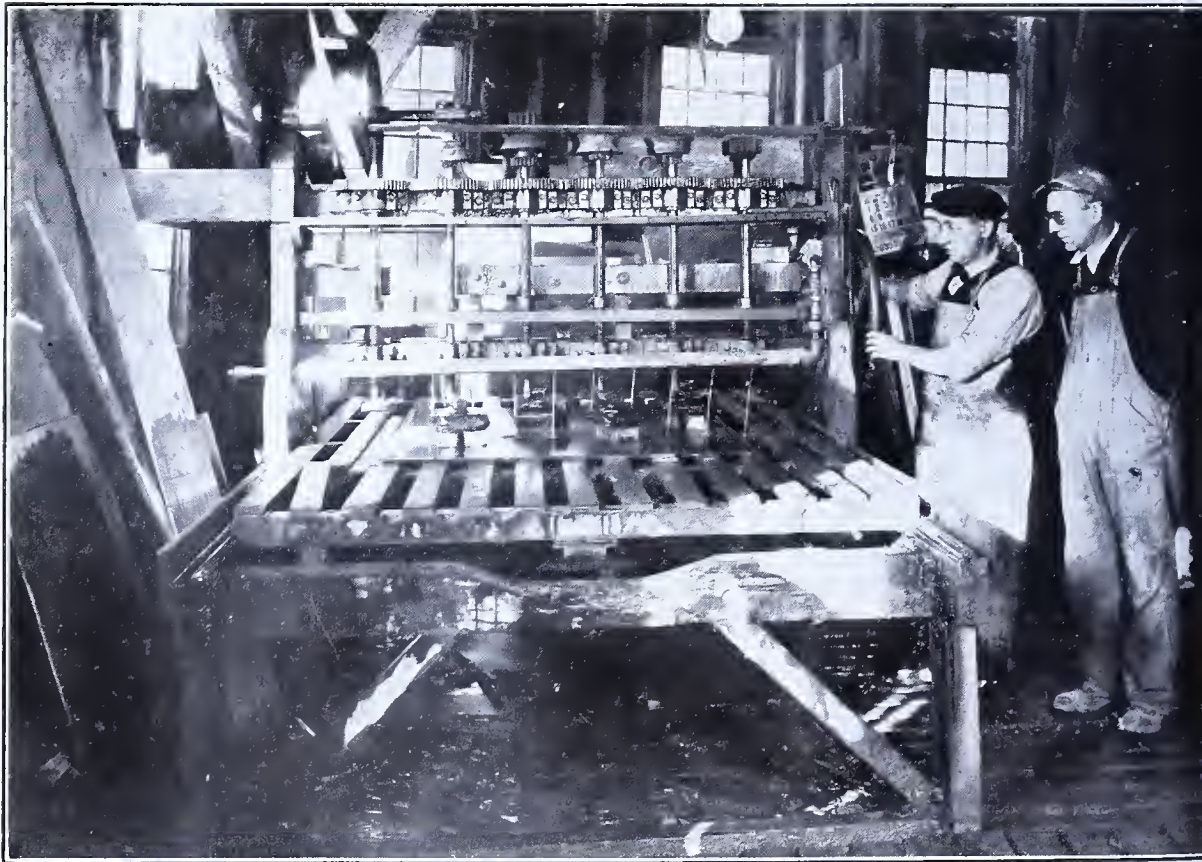
A. Planing machine in operation.



B. Rubbing bed; a slate slab is resting on the disk-shaped rubbing surface and another is held by the operator with its edge against the surface of the rubbing disk. Photographs by Bliss, Easton, Pa.



A. Bread board of soft slate; diameter 24 inches.



B. Multiple-head buffer; only four arms are in use.

Recently attention has been directed to the waste of sand in the run-off. One quarry solved this problem by installing a cone system for sand recovery¹.

Buffing. To give a final polish a buffing machine is used on the slate. This is necessary only in the case of blackboards, bulletin boards, and switchboards.

Buffing machines are of two types. One of these, the Vermont type, consists of a disk-shaped head in which are mounted blocks of abrasive material. This polishing head is rotated by a belt connected with a power-driven shaft and is attached to a movable vertical arm. Pressure of buffer against slate surface is supplied by a heavy spring, upon which the operator exerts traction. Water is directed upon the slate while the polishing is in progress. This type of buffer requires careful operation and finishes only a small area at a time.

The other type has several arms or rods (generally six), each carrying a polishing block. When smaller pieces are polished not all six arms are needed but in such cases those not in use are generally left in gear. The arms rotate around vertical axes so that each polishing block acts on a circular area. From time to time the slab is moved until it has all been gone over in this way.

Carborundum wheels. These are employed in many mills for beveling and for cutting small slabs of slate to the desired size. They are coming into increasing use. In some instances they are placed on travelling axles, so that the slate can be fixed and the wheel forced against it mechanically.

Shaping and drilling. As a final stage in beveling, shaping, grooving or fitting slate for switchboards or for tubs, sinks, and troughs, hand work is resorted to. Perhaps the greatest skill in the slate industry is needed for these finishing steps. In many mills drilling for wiring or bolting is also done by hand, but some factories use mechanical drills, which are multiple in some cases, permitting the simultaneous drilling of several holes at set distances.

Electrical slate testing. By empirical methods the beds capable of yielding electrical slate are known. The outstanding characteristics of these beds are their uniformity of grain and the absence of magnetite and pyrite, of excessive graphite, and of small areas bearing more than normal quantities of silica. Although most of these undesirable features can be easily recognized upon superficial inspection, they are frequently not seen when present, especially if the slab is thick and conceals them in its interior. For testing the electric insulation of slate, a special apparatus consisting of a transformer, milliammeter, and two wires with brush-like terminals has been devised by Robert Notvest, working for the Structural Slate Company².

A wire is applied to one side of the slab, and with the other wire all points on the slate surface are brushed over to see whether there is any leakage. This is determined by the flow of current recorded on the milliammeter.

Electrical testing of slate is described in detail on page 80-81.

¹ Mimeographed report of Committee D-16 on Slate, Am. Soc. Test. Mat., Jan. 19, 1931, pp. 6, 7.

² Notvest, Robt., Slate for electrical uses, publ. by the Structural Slate Company, Pen Argyl, Pa., 1924, pp. 33-34.

Blackboard making. Blackboards are split like roofing slate, but more care must be exercised because the slabs are generally larger. They are then sand-rubbed on the rubbing bed, polished under the buffer, and stored in a separate shed. In one factory the old practice of hand planing the slate for blackboards is still followed. For this purpose a sharp blade with long cutting edge is used. Blackboards must be carefully crated for shipping.

School slates. These are made from beds darker than the usual light-gray slate, but not as dark as the "ribbon" or highly carbonaceous layers. The slate is split, like roofing slate, and then trimmed with a rapidly rotating saw shaped like a square with a triangular prolongation at each corner. The sizes of school slates vary from 4 x 6 inches to $9\frac{1}{2}$ x 14 inches. "Toy blackboards" measure 18 x 20 inches.

Each piece of slate is first sent through a beveler; this bears a carriage by which the slate is propelled over knives which have their blades inclined in such a way that one edge of the slate is beveled in transit.

When the piece has been beveled on all edges, it is forced between two knives placed with their blades only far enough apart to permit the passage of the desired thickness of slate ($\frac{1}{6}$, $\frac{1}{7}$, and $\frac{1}{8}$ inch, according to the grade specified). This machine is called the shaver.

For final surfacing the beveled and shaved slate may be passed between two paper covered cylinders which rotate rapidly in opposite directions; this machine acts as a buffer.

Some slates are ruled, especially if destined for use in Continental Europe. The grooves of the rulings are colored with red lead. The last step before framing is a thorough washing.

School slates destined for domestic use are framed here as well, and a bit of colored goods is applied to the outside of the frame. Foreign slates are set in wire-bound frames. The finished slate is carefully packed in boxes.

In recent years two school slate factories have operated between Slatington and Slatedale and one near Flicksville, south of Bangor. The largest is that near Slatington.

Accessory machinery and sheds. Well-equipped slate mills generally have an emery or carborundum wheel for sharpening saws and planer knives. A separate room is ordinarily supplied for fitting work, such as hand turning and beveling of mill products. Similarly, the workers splitting blackboards are commonly given a separate workshop. A lumber shed and carpenter shop with buzz saw are also present, and here slate is crated for shipping. Adjacent to the rubbing bed is a sand house, with a chute leading to the factory.

Storage. Finely-finished mill products are stored in a room or house connected with the factory by rail. A separate space fitted with racks is set aside for blackboard storage.

MARBLEIZING PLANTS

In the later part of the last century much "marbleized" slate was produced. It consists of slate the surface of which has been stained or painted in various designs; after these have been put on the slate, they are baked in. Marbleized slate was formerly much in fashion and

is still used for mantles, wainscoting, table tops, tiles, and door plates, as well as for checker boards and in X-ray panels.

As practiced by the Butler Brothers Company at Pen Argyl, the first step in marbleizing was to apply a ground coat of color on finished structural slate. The desired pigments in oil were dropped on the surface of water in a vat. The film of color thus formed was broken by agitation; then the slate slab was gently lowered, face down, upon the network of paint floating on the surface of the water. This network adhered to the face of the slab when the latter was withdrawn. In this manner the appearance was simulated of, for example, a piece of verde antique. The surface was then finished by heating in a kiln, varnishing, and polishing with pumice.

Since 1926 the Structural Slate Company at Pen Argyl has manufactured a similar product. Structural slate with or without ribbons may be used and an outlet is thus furnished for ribboned blocks. These are finished smooth and coated with a lacquer applied as a spray by means of compressed air. Several coats of varying colors may be applied for mottled or blended effects. A two-tone marble-like imitation is also made by using one color (as, for example, black) as a base and transferring upon this in another color (such as golden-yellow) a vein-like pattern received from a copper plate upon which the design was reproduced from a photograph of a marble slab. The final appearance is thus a good imitation of true "vein" marble. A transparent coat of lacquer is applied last.

GRANULATING AND PULVERIZING MILLS

Slate granules. In 1927 two plants in Pennsylvania made slate granules. These were located at Pen Argyl, in Northampton County, and at West Bangor, near Delta, York County. A third large plant at Whitaker, just south of the Pennsylvania line in the Peach Bottom district, was also active. In addition, crushing and pulverizing plants have in recent years been operated at Peach Bottom, Lancaster County, in the Peach Bottom district; at Lenhartsville, Greenawald, and Albany, in Berks County; near Bangor, Northampton County; and just east of the Pennsylvania line at Columbia, New Jersey, opposite Portland, Pennsylvania.

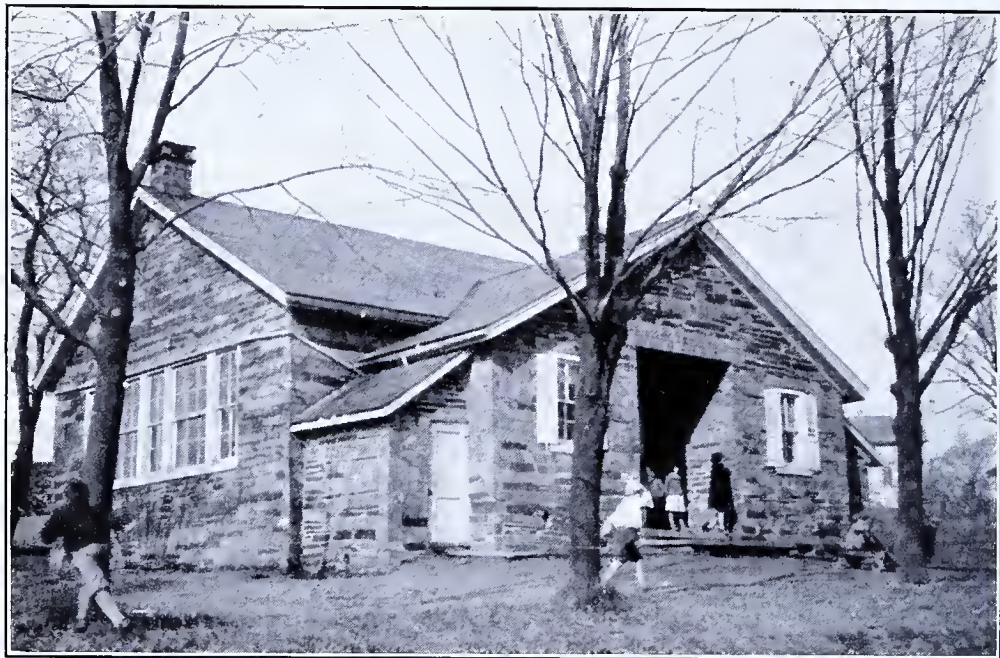
The general plan is to feed waste or the normal broken quarry product into a gyratory crusher, then to a hammer mill, disk, rolls or other secondary crusher and sometimes, as at the Parsons Brothers' plant, Pen Argyl, directly to a ball mill. For sizing, the product is screened, the "hummer" type of screen being preferred. Two sizes are produced,—granules and dust, and some plants yield a middling as well.

The three plants located in Berks County all produced red and, to a small extent, green granules. Most of the product, however, was dried and finely crushed¹.

Slate granules are used for surfacing flexible stone-coated shingles and roll roofing.

Pulverized slate. All of the mills mentioned have produced pulverized slate. It is the fine product from the secondary or finer crushing mentioned above. It is used mainly as a filler for paint, linoleums,

¹ See also, Stone, R. W., Roofing granules in southeastern Pennsylvania: Pa. Top. and Geol. Survey Mimeographed Bull. 82, 4 pp., 1923.



A. Schoolhouse at Chapman, Northampton County, built of waste blocks from hard slate quarries.



B. Typical waste heap. Albion quarry, Keenan Structural Slate Co., Pen Argyl.

and rubber. Some also enters fuse covers, and occasionally is a substitute for fuller's earth. The red slate of Lenhartsville once even was treated for iron. Crushed sizes coarser than dust are generally regarded as waste, but have been used locally for brick making.

WASTE

Reduction. Waste reduction is the largest single problem of the slate industry. The waste incidental to quarrying is enormous and even that resulting from milling is conspicuously great. Together they are estimated to equal between 60 and 85 per cent of all the slate taken from the ground¹. Some of this loss is inevitable, being due partly to irregularities in cleavage, jointing, or some other structural feature, partly to sedimentary factors, such as "ribbons", "hard rolls", and "knotty" slate. Much may be assigned to inadequate exploration in advance of quarrying. This and poor mill practice—another source of waste—both lie within human control.

Utilization. Bowles² has discussed extensively possible methods of utilizing the slate hitherto thrown away. He mentions the following products in which waste slate may be successfully used:

- Inlaid slate roofs
- Flagging
- Fence posts
- Wall rock, for placing in the walls of buildings as a heat insulator
- Rubber filler, when pulverized
- Linoleum, oil cloth, and window shade filler (except where these must be white), when pulverized
- Filler in plastic roofing and flooring
- Bonded briquets for road laying
- Filler in sheet surface mixtures in road asphaltting
- Brick and tile
- Synthetic slate
- Filler in metal polish
- Abrasive soap
- Filler in wrapping paper and cardboard
- Foundry sand mixtures
- Granules in synthetic roofing

Several other possible uses, such as inlaid slate, slate lathing, and slate-surfaced shingles have also been suggested. In several places in the slate district, slate blocks are actually substituted for wood or brick in the walls of houses. The schoolhouse at Chapman, Northampton County, illustrates this use.

Disposal. The matter of waste disposal has already been touched upon under quarry and shanty practice. It suffices to say that waste accumulates in quarry, shanty, and mill. This waste is disposed of as follows:

1. Waste from quarry operations is dumped at the end of an incline leading away from the quarry or is thrown back into those parts of the opening which have been abandoned.

2. Waste from roofing slate making is dropped beside the shanties, the trimmer in each shanty simply throwing it out through the chute provided for that purpose. In modernized practice it is carried to the dump by car or traveling belt.

¹ Bowles, Oliver, op. cit., p. 83; Ries, Heinrich, Economic geology, p. 162, 1930; Merrill, G. P., Stones for building and decoration, p. 189, 1910.

² Op. cit., pp. 82-107.

3. Waste from the mill is disposed of like that from the quarry.

Generally the dump on which the larger blocks of waste from the quarry and the mill are thrown is in the form of an incline, up which small ears bearing the material to be discarded are either pushed by hand or hauled by horse or cable.

It is especially important to avoid placing waste piles above slate reserves still in the ground, which might necessitate rehandling the discard before further quarrying.

DESCRIPTIONS AND SPECIFICATIONS OF SLATE PRODUCTS

ROOFING SLATE

The following sizes and specifications are jointly from standard price lists of the larger roofing slate distributing companies in Pennsylvania and from a publication of the Bureau of Standards¹.

Standard sizes for roofing slate

| Inches. | Number per square. | Exposure** Inches. | Nails to square (3-d). Lbs. oz. | Inches. | Number per square. | Exposure** Inches. | Nails to square (3-d). Lbs. oz. |
|---------|--------------------|--------------------|---------------------------------|----------|--------------------|--------------------|---------------------------------|
| 24 x 14 | 98 | 10½ | 1 0 | 16 x 8 | 277 | 6½ | 2 12 |
| 24 x 12 | 115 | 10½ | 1 2 | *14 x 14 | 187 | 5½ | 1 13 |
| 22 x 14 | 109 | 9½ | 1 3 | 14 x 12 | 218 | 5½ | 2 3 |
| 22 x 12 | 126 | 9½ | 1 4 | 14 x 10 | 261 | 5½ | 2 9 |
| 22 x 11 | 138 | 9½ | 1 6 | 14 x 9 | 290 | 5½ | 2 14 |
| 20 x 14 | 121 | 8½ | 1 7 | 14 x 8 | 327 | 5½ | 3 3 |
| 20 x 12 | 141 | 8½ | 1 8 | 14 x 7 | 374 | 5½ | 3 11 |
| 20 x 11 | 154 | 8½ | 1 6 | *12 x 12 | 266 | 4½ | 2 9 |
| 20 x 10 | 169 | 8½ | 1 11 | 12 x 10 | 320 | 4½ | 3 2 |
| 18 x 12 | 160 | 7½ | 1 9 | 12 x 9 | 356 | 4½ | 3 8 |
| 18 x 11 | 175 | 7½ | 1 11 | 12 x 8 | 400 | 4½ | 3 15 |
| 18 x 10 | 192 | 7½ | 1 14 | 12 x 7 | 457 | 4½ | 4 8 |
| 18 x 9 | 213 | 7½ | 2 1 | 12 x 6 | 533 | 4½ | 5 4 |
| 16 x 12 | 185 | 6½ | 1 13 | 10 x 8 | 515 | 3½ | 6 5 |
| 16 x 10 | 221 | 6½ | 2 3 | 10 x 7 | 588 | 3½ | 6 5 |
| 16 x 9 | 246 | 6½ | 2 7 | 10 x 6 | 686 | 3½ | 6 5 |

* Not officially recommended.
** Exposure when laid and spacing of lath.

For flat roofs standard dimensions are 3/16 in thickness, with the following face dimensions, in inches:

| | | |
|-------|--------|--------|
| 6 x 6 | 10 x 6 | 12 x 6 |
| 6 x 8 | 10 x 7 | 12 x 7 |
| 6 x 9 | 10 x 8 | 12 x 8 |

Slate for roofing is sold by a unit called the square,—the slate necessary to cover 100 square feet with a 3-inch overlap. The standard thickness is 3/16 inch. Thicker slates are supplied on demand, the usual thickness being ¼ and ⅜ inches. The weight per square is between 625 and 725 pounds.

The surface of a roofing slate parallels the cleavage. In some quar-

¹ Roofing slate: U. S. Bur. Standards Simplified Practice Recommendation R 14-28, p. 1, 1928.

ries cleavage is locally curved; this results in curved slates, which can be used if carefully laid. In imitating old structures, architects occasionally demand such curved cleavage, but for ordinary use it is less desirable than perfectly plane cleavage.

The following specifications are to be looked for under the trade terms when roofing slates from the Lehigh-Northampton district are purchased:

No. 1 Clear: Tolerably uniform as to surface; thickness about $3/16$ inch; straight, with clean corners; entirely free of ribbons.

Semi-Clear: Same as "No. 1 Clear," but may have ribbons which in this case lie above the nail holes and hence are hidden by the overlap.

No. 1 Ribbon: Similar in quality and appearance on the roof to "Clear" and "Semi-clear" grades, the only difference being that some of the ribbons come below the nail holes.

In addition most quarries supply a lower grade, called largely "No. 2 Ribbon," which shows ribbons below the nail holes and below the overlap; when such slate is laid on a roof the ribbons may be visible; hence it is more commonly used for roofing barns and sheds. "No. 2 Clear" slate is such as has been culled from "No. 1 Clear" because of curved cleavage, chipped corners, or thickness in excess of the standard $3/16$ inch.

In the "hard" belt of the Lehigh-Northampton district no ribbonless slates are produced, but the ribbons are generally not conspicuous after appreciable weathering. These slates are classed as No. 1 and No. 2 on the basis of the smoothness of the surface; highly siliceous ribbons generally warp such a surface slightly and make a No. 2 slate.

In the Peach Bottom district only clear stock is made.

Architects are calling for rough slates, broken slates, slates of exceptional thickness, and slates made from the "hard rolls" (sandy portions) of beds, but these special orders have not been standardized.

ELECTRICAL SLATE

The following is a digest of the specifications suggested by the largest electrical slate producer in the State:

1. The slate should be clear stock, uniform in color free from veins, spots, and cracks; specific gravity about 2.8. Absorption of water by weight in 24 hours should not exceed 0.3 per cent. Tensile strength 3500 lbs. per square inch. Modulus of elasticity 8,000,000 lbs. per square inch. Toughness 12 (method advocated by the American Society for Testing Materials). Coefficient of expansion 0.000002°C . or equivalent. Heat resistance to withstand 200°C . without cracking.

2. Slate should not be used for electrical purposes until three months after quarrying.

3. Faces and edges of panels must be true surfaces, accurately cut to dimensions and varying not over $1/16$ inch. Adjoining edges shall not deviate from a right angle by more than $1/32$ inch. Bevels shall be cut true entirely around panels; they shall be measured by the projected width and depth. Back of panels shall be free from lumps or depressions, but need not be trued.

4. All slate shall be electrically tested prior to shipment with one of several specified devices, and impedance leakage actually measured

5. Holes drilled in the slate for securing or fastening it shall be 15-20 per cent larger in diameter than the screws, bolts, and other appliances used. Compressible washers shall be used between the slate and the framework.

6. Large slabs four square feet or over in area shall be so supported that the fastening screws or other appliances shall not bear the weight of the slate; large switchboard assemblies shall rest on a substantial iron base, preferably cushioned.

Special devices for testing the impedence and ohmic resistance of slate have been prepared by Mr. Robert Notvest, acting for the Structural Slate Company.

Slate to be used for electrical purposes must be free of "ribbons" and of larger quantities of magnetite and pyrite (as in veinlets), and it should be dried of its quarry water. There appears to be no objection to silicea in electrical slate when it is uniformly distributed and not localized in veins or beds.

STRUCTURAL AND SANITARY SLATE

For structural and sanitary use, slate should be soft, evenly grained, and preferably not too heavily ribboned. The slate is taken out of the factory in four finishes,—sand rubbed, honed, and, when polished, in "black enamel" and "white enamel" finishes. It may also be marbled by a special process. Less finished and less expensive surfaces are the following, which can generally be supplied on demand:

Sawed edges: This surface consists of concentric groovings, as left by the hack-saw; such surfaces may be used in copings and nosings,—generally outdoor finishes.

Split-face surface: This is rough to appearance and touch; it is the finish left on roofing slate. It is in demand for outside flagging, steps, and walks.

Planed surface: This is smoother than the split-face surface, having no minor roughnesses that can be felt, but the parallel marks of the planing knife can be seen faintly.

It should here be stated that although clear stock may be used for structural purposes, ribboned slate is said to be equally satisfactory in its weathering qualities and is more readily obtainable. In the Lehigh-Northampton district it is less costly as approximately 80 per cent of the slate from quarries bears ribbons.

As among the structural and sanitary uses to which slate may be converted, the following may be mentioned: toilet appliances, shower stalls, sinks, tubs, vats, shelving, copings, hearths, stairs, tables and lithographic stone.

GRAVE VAULTS AND BILLIARD TABLE TOPS

For grave vaults, the specifications and trade practice in the soft belt are similar to those applied to structural and sanitary slate. In the hard belt the finish is like that described under "Split-face surface" (see "Structural and Sanitary Slate" above), as no milling is given the hard belt structural slate.

The qualifications for billiard table tops are simply that the slate be obtained in large slabs free from joints and veins, that it be soft, and able to take a smooth polish.

SCHOOL SLATES

For school slate use, slate should be dark and free from knots and ribbons. These slates occur commonly in smaller beds. The beds in the soft belt of sections of Northampton County are generally less well adapted to this type of product than those at Slatington. However, at least one quarry at Bangor yields appreciable quantities of school slate.

BLACKBOARDS AND BULLETIN BOARDS

Slate for blackboards and bulletin boards should be free from ribbons, of fairly dark gray color, soft, highly fissile, and preferably with plane cleavage. If the cleavage is gently curved, which is not infrequently the case, the boards may be "sprung" into position because of the elasticity of the slate, and are then as satisfactory as though the cleavage were wholly plane. The sizes of blackboards vary, but standard sizes are 3 feet, 3 feet 6 inches, and 4 feet in width and 4 feet 6 inches or less long, with thicknesses of $\frac{1}{4}$ inch to $\frac{3}{8}$ inch.

CRUSHED SLATE

Slate granules, with pulverized slate and similar ground products, depend for specifications wholly on the use to which they are to be put.

PRODUCTION

From Pennsylvania quarries and mills all varieties of slate products except slate pencils are obtained. The list includes roofing slate, mill stock, marbleized slate, slate granules, and pulverized slate. "Mill stock" is a comprehensive term covering rough or finished slate that is used for structural purposes or in interior furnishings of buildings. It includes slate for structural and sanitary purposes (e. g., sinks, mantels, dripboards, shower stalls, toilet stalls, stair risers, insulating wall boards, and the like), grave vaults and covers, billiard table tops, electrical insulation and switchboard material (together classed as "electrical slate"), blackboards and bulletin boards (lumped together under the trade term of blackboards), school slates, marbleized slate, crushed slate, and ground slate. Among the districts where slate is now being quarried the "soft" slate of the Lehigh-Northampton district yields all of these products; the Peach Bottom district and the "hard" belt in the Lehigh-Northampton district furnish today only crushed slate, roofing slate, and slate for such structural and sanitary uses as will require no finishing, although finished structural slate and even blackboards were once prepared with the aid of diamond saws at the Chapman quarry in the "hard" belt. The great proportion of the slate production of the State is in the form of roofing slate.

The statistics and curves below give figures obtained from the U. S. Geological Survey and the U. S. Bureau of Mines¹.

They represent the quantity or values sold in the year stated, and so do not give the actual production, which may be more or less, according to whether the producer is overstocked at the end of the year or draws on supplies of the preceding year for sales. Values quoted are f. o. b. at point of shipment.

Before considering the figures for Pennsylvania, taken by itself, attention may be directed to several general features in the slate production of the United States as a whole. The curve (Figure 34) brings out certain features. First, estimates indicate that virtually the entire value of slate production prior to 1888 is represented by the value of roofing slate; in later years, however, the relative importance of roofing

¹ Mineral Resources of the United States: U. S. Geol. Survey, prior to 1924. Mineral Resources of the United States: U. S. Bur. Mines, 1924-1930.

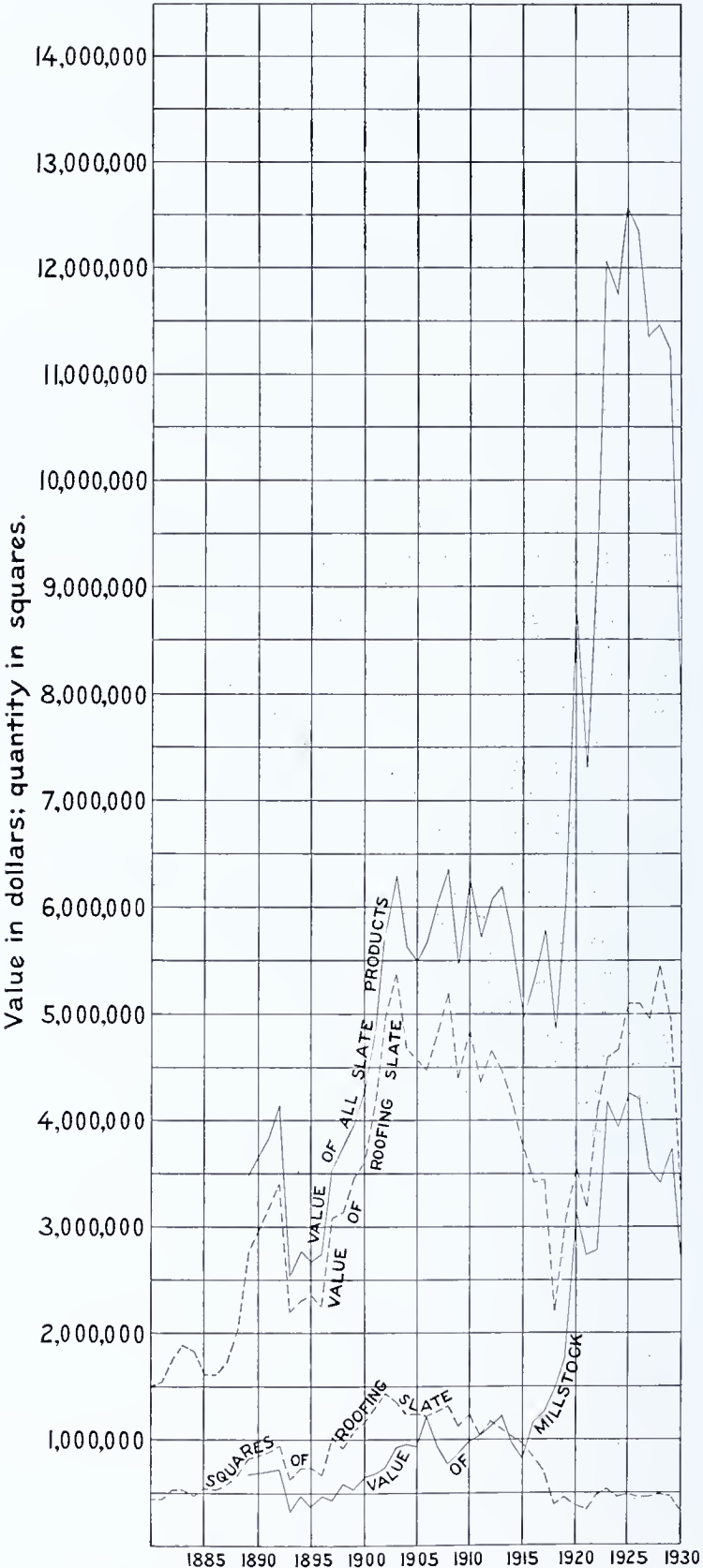


Fig. 34. Value of slate production in the United States, by classes.

slate declined and that of other slate products increased. The rise in the value of millstock is especially noteworthy between 1915 and 1923.

It is also noteworthy that, although the amount of roofing slate reached its peak in 1902, the value of roofing slate, though suffering temporary set-backs, has maintained an average level not far below this peak. In other words, the price has risen to some extent to balance the decline in volume of production.

The decline of roofing slate, which set in in 1903, probably represents competition from other roofing materials. Since 1922 the annual sales have remained almost constant and it is at least probable that they will continue so when taken over long time periods.

Pennsylvania production. Pennsylvania leads all other States in slate production. Between 1913 and 1929, inclusive, the value of slate produced amounted to \$70,177,163 as against \$146,905,919 for the country as a whole,—or approximately 47 per cent.

Pennsylvania leads all other states in the production of all kinds of products except electrical slate and slate pencils. A comparison of the value of slate produced in Pennsylvania is given in Figure 35. In the

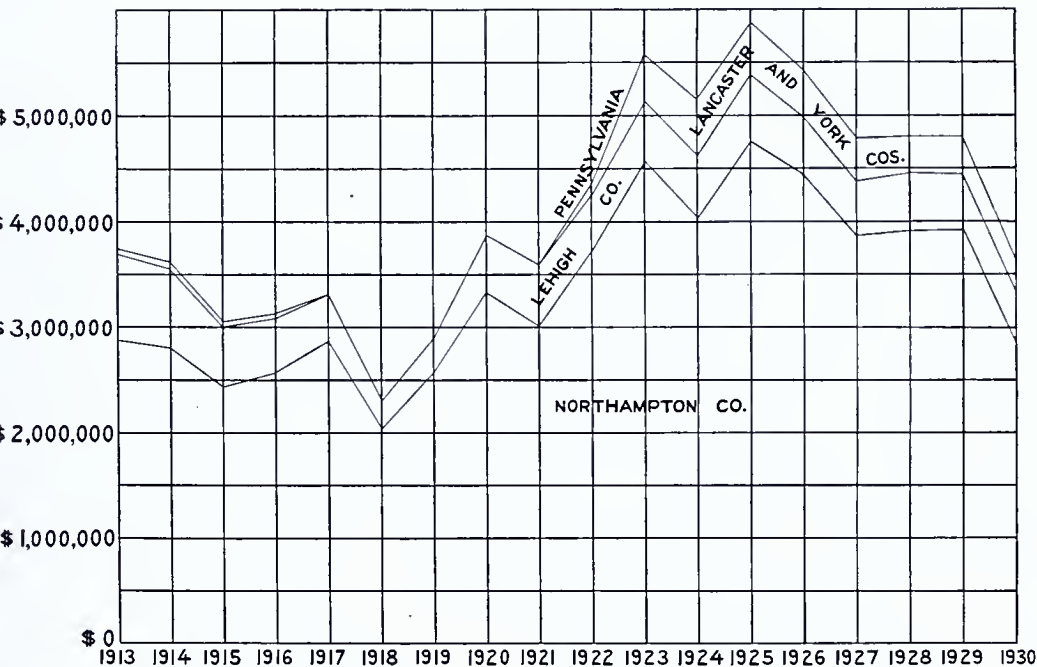


Fig. 35. Value of slate production in Pennsylvania,—the state and the individual districts.

data Lehigh and Northampton Counties are separated. Figures from the Peach Bottom district are separated until 1917; thereafter they are lumped with all of the granules and pulverized slate from other parts of the State.

Roofing slate. In recent years Pennsylvania quarries have produced annually about 40 per cent of the slate quarried in the United States, and Northampton County accounts for about 38 per cent. In very recent years there has been no production from that part of the Peach

TABLE 1.
Production of roofing slate, 1913-1931.

| Years | Squares (100 square feet) | | | | | Value in dollars | | | | |
|-------|---------------------------|---------|----------------------|---------------------|--------------|------------------|-----------|------------------------|----------------------|--------------|
| | U. S. | Penn. | Northampton Co. | Lehigh Co. | Peach Bottom | U. S. | Penn. | Northampton Co. | Lehigh Co. | Peach Bottom |
| 1913 | 1,113,944 | 678,396 | 525,286 | 143,145 | 9,965 | 4,461,062 | 2,605,882 | 2,035,796 | 513,027 | 57,059 |
| 1914 | 1,019,553 | 614,863 | 478,216 | 125,148 | 11,489 | 4,160,832 | 2,463,944 | 1,942,555 | 461,029 | 60,360 |
| 1915 | 967,880 | 574,223 | 452,278 | 113,911 | 8,634 | 3,746,334 | 2,142,173 | 1,695,589 | 401,345 | 45,239 |
| 1916 | 835,873 | 531,342 | 428,968 | 98,471 | 3,903 | 3,408,934 | 2,066,324 | 1,667,738 | 367,896 | 20,780 |
| 1917 | 703,667 | 457,393 | 397,349 ¹ | 60,044 | * | 3,411,740 | 2,110,044 | 1,829,956 ¹ | 280,088 | * |
| 1918 | 379,817 | 211,196 | 189,648 | 21,548 | * | 2,219,131 | 1,161,545 | 1,042,719 | 118,826 | * |
| 1919 | 454,337 | 269,580 | 247,293 | 22,287 ¹ | | 3,087,957 | 1,679,519 | 1,543,750 | 135,769 ¹ | |
| 1920 | 396,230 | 229,366 | 201,821 | 18,545 | | 3,524,658 | 1,746,026 | 1,601,030 | 144,996 | |
| 1921 | 348,085 | 202,605 | 180,894 | 21,711 | | 3,197,745 | 1,595,169 | 1,407,283 | 157,826 | |
| 1922 | 479,243 | 283,365 | 256,531 | 26,834 | | 4,069,761 | 2,076,585 | 1,888,163 | 188,422 | |
| 1923 | 507,587 | 300,272 | 278,029 | 22,243 | | 4,582,535 | 2,373,125 | 2,201,515 | 171,610 | |
| 1924 | 469,393 | 249,450 | 222,616 | 26,834 | | 4,626,614 | 2,620,986 | 1,801,998 | 218,988 | |
| 1925 | 494,530 | 287,120 | 266,820 | 20,300 | | 5,084,945 | 2,316,856 | 2,138,352 | 178,504 | |
| 1926 | 465,990 | 263,668 | 247,738 | 15,930 | * | 5,079,087 | 2,127,782 | 1,999,965 | 127,817 | * |
| 1927 | 468,560 | 247,120 | 226,200 | 20,920 | | 4,949,940 | 1,933,076 | 1,803,184 | 149,892 | |
| 1928 | 483,280 | 256,540 | 233,630 | 22,910 | | 5,411,332 | 2,633,588 | 1,875,467 | 158,121 | |
| 1929 | 462,120 | 251,880 | 232,990 | 18,890 | | 4,920,766 | 1,967,428 | 1,832,428 | 135,000 | |
| 1930 | 340,140 | 194,700 | 179,340 | 15,360 | | 3,359,939 | 1,470,669 | 1,370,736 | 99,933 | |
| 1931 | 277,700 | 183,600 | 160,670 | 22,930 | | 2,364,861 | 1,254,080 | 1,126,451 | 127,629 | |

* Some production but not separately published.

¹ Includes some production from Peach Bottom district.

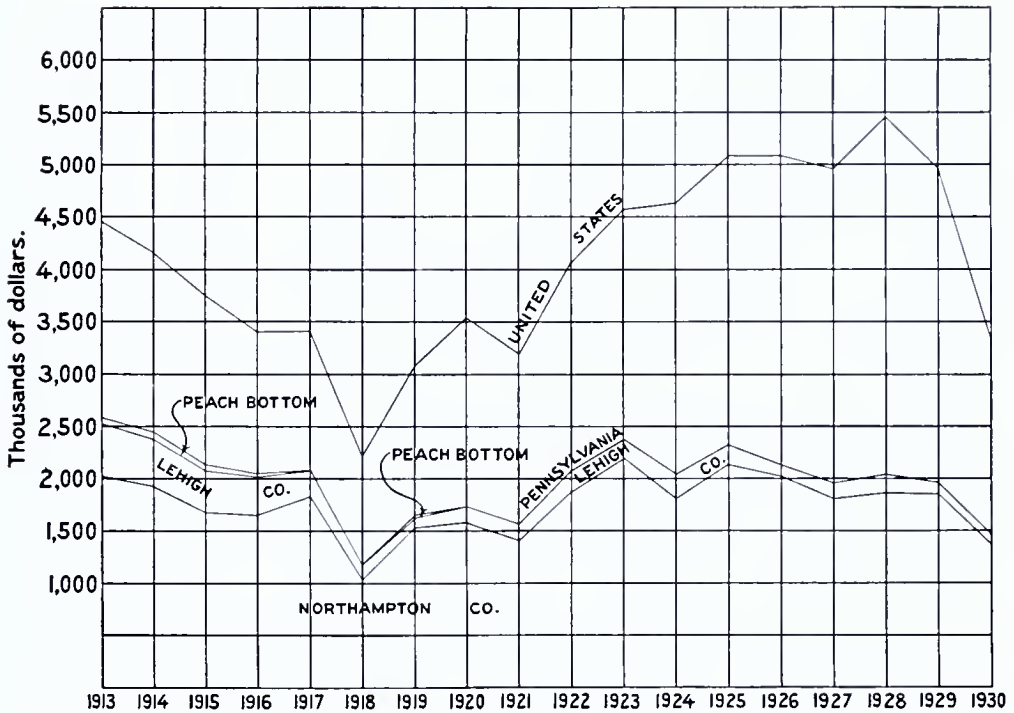


Fig. 36. Value of roofing slate production in the United States, Pennsylvania, and Pennsylvania districts.

Bottom district that is in Pennsylvania. Figure 36 illustrates this relationship graphically. The table given on page 112 shows the production of roofing slate in the three leading regions, in the State as a whole, and in the United States.

Millstock. As commonly used, this term denotes all milled slate, including electrical and school slate, backboards and bulletin boards. In this section and the appended table, however, it is restricted to structural and sanitary slate, grave vaults and covers, as separate sections are devoted to each of the other types of millstock mentioned.

In normal years Pennsylvania furnishes approximately 90 per cent of the total American production of millstock, both in value and in quantity. Northampton County quarries yield about 88 per cent of that total. Some idea of the relative importance of Pennsylvania is obtained from Table 2, which presents comparative data for Lehigh and Northampton Counties.

Blackboard and bulletin board slate. Pennsylvania is the only State commonly producing blackboard slate, although very small amounts have come from other localities in certain years. The yield is entirely from the Lehigh-Northampton district, the ratio of the production of Lehigh and Northampton counties being approximately 1:5 in later years. All of the production comes from the neighborhood of Bangor, of Pen Argyl and Wind Gap, or of Slatington, Berlinsville, and Slatedale. Since much of the latter district is in Northampton County, the production ratio of the eastern to the western part of the Lehigh-Northampton district is slightly lower than indicated for Lehigh and Northampton counties. In the past small amounts have also been produced

TABLE 2.

Value in dollars of structural slate produced in Pennsylvania, in 1917-1931.

| Year | United States | Pennsylvania | Northampton County | Lehigh County |
|------|------------------------|----------------------|----------------------|---------------------|
| 1917 | 1,277,249* | 710,092 ¹ | 665,072 ¹ | 45,020 ¹ |
| 1918 | 1,498,164 ¹ | 686,999 | 671,481 | 15,518 |
| 1919 | 708,640 | 676,301 | 654,631 | 21,670* |
| 1920 | 1,047,011 | 1,005,400 | 992,230 | 13,170 |
| 1921 | 764,499 | 720,462 | 702,312 | 18,150 |
| 1922 | 838,416 | 761,935 | 741,993 | 19,942 |
| 1923 | 1,005,974 | 885,809 | 858,723 | 27,086 |
| 1924 | 1,094,131 | 996,460 | 977,868 | 18,592 |
| 1925 | 987,601 | 896,087 | 865,651 | 30,436 |
| 1926 | 1,119,403 | 997,108 | 974,936 | 22,172* |
| 1927 | 1,085,524 | 923,888 | 882,456 | 41,432 |
| 1928 | 1,171,654 | 999,766 | 968,431 | 31,335 |
| 1929 | 1,420,181 | 1,135,695 | 1,101,474 | 34,221 |
| 1930 | 1,045,237 | 822,391 | 809,070 | 13,321 |
| 1931 | 715,529 | 550,005 | 526,826 | 23,179 |

* Includes a small production from Lancaster Co.

¹ Includes some electrical slate.

in the "hard" belt of this district, but the demand for this has greatly declined. The table below gives the figures for each county and for the State as a whole.

TABLE 3.

Production of blackboards and bulletin boards, 1913-1931.

| Year | Square feet | | | Value, dollars | | |
|------|--------------|--------------------|---------------|----------------|--------------------|---------------|
| | Pennsylvania | Northampton County | Lehigh County | Pennsylvania | Northampton County | Lehigh County |
| 1913 | 3,504,162 | 2,108,315 | 1,295,847 | 426,793 | 279,584 | 147,119 |
| 1914 | 4,021,047 | 2,309,844 | 1,711,203 | 526,846 | 330,001 | 196,845 |
| 1915 | 3,152,771 | 2,247,575 | 905,196 | 349,959 | 271,715 | 78,244 |
| 1916 | 3,182,159 | 2,476,113 | 706,046 | 403,502 | 327,355 | 76,147 |
| 1917 | 2,650,563 | 1,976,265 | 674,298 | 413,163 | 332,385 | 80,778 |
| 1918 | 1,592,849 | 1,294,159 | 298,690 | 262,221 | 222,244 | 39,977 |
| 1919 | 1,845,687 | 1,622,221 | 223,466 | 304,251 | 259,319 | 44,932 |
| 1920 | 2,251,646 | 1,880,249 | 321,462 | 384,131 | 371,397 | 62,669 |
| 1921 | 3,154,261 | 2,549,458 | 604,743 | 791,241 | 681,625 | 109,616 |
| 1922 | 3,158,218 | 2,999,782 | 518,436 | 880,596 | 784,942 | 95,654 |
| 1923 | 4,415,550 | 3,872,213 | 543,367 | 1,186,326 | 1,079,443 | 106,883 |
| 1924 | 4,064,520 | 3,439,830 | 624,690 | 1,149,810 | 1,023,202 | 126,608 |
| 1925 | 5,083,330 | 4,337,410 | 745,890 | 1,689,336 | 1,503,490 | 185,846 |
| 1926 | 3,998,653 | 3,229,762 | 768,891 | 1,356,300 | 1,202,221 | 154,079 |
| 1927 | 2,735,870 | 2,999,380 | 726,490 | 1,116,598 | 954,260 | 162,338 |
| 1928 | 2,713,840 | 2,793,970 | 919,870 | 1,079,452 | 884,479 | 194,973 |
| 1929 | 3,562,360 | 2,637,240 | 925,120 | 1,042,771 | 849,708 | 193,063 |
| 1930 | 3,692,880 | 2,401,970 | 690,910 | 921,735 | 788,977 | 132,758 |
| 1931 | 2,357,070 | 1,674,700 | 682,370 | 640,593 | 506,053 | 134,540 |

Electrical slate. Vermont, Maine, and Pennsylvania are the chief producers of electrical slate. In this field Pennsylvania takes third place and Vermont has generally been the leader. The following table compares the production of electrical slate of these three States and of the United States as a whole. (Table 4, page 115).

School slate. This comes from certain very dark beds which have a limited distribution. Pennsylvania is the only state in which it is quarried. The district to which production is credited depends upon the location of the school slate factory at which the slate is finished. This accounts for fluctuations in the reported production of the two counties as listed below. At present all of the school slate factories are west of Lehigh River, in Lehigh County, near Slatington.

TABLE 4.

Value of electrical slate production in dollars, 1918-1931.

| Year | United States | Vermont | Maine | Pennsylvania |
|------|---------------|-----------|-----------|--------------|
| 1918 | \$771,003 | \$339,064 | \$260,059 | \$171,880 |
| 1919 | 607,796 | 257,975 | 234,888 | 114,933 |
| 1920 | 1,491,769 | 653,351 | 396,692 | 441,726 |
| 1921 | 927,951 | 353,133 | 358,547 | 216,271 |
| 1922 | 996,322 | 403,453 | 361,595 | 231,274 |
| 1923 | 1,754,717 | 769,146 | 737,610 | 453,070 |
| 1924 | 1,518,092 | 566,526 | 585,004 | 366,562 |
| 1925 | 1,376,948 | * | * | 346,513 |
| 1926 | 1,537,034 | * | * | 327,447 |
| 1927 | 1,155,702 | * | * | 228,559 |
| 1928 | 1,025,386 | * | * | 211,588 |
| 1929 | 1,153,396 | * | * | 219,761 |
| 1930 | 711,578 | * | * | 99,577 |
| 1931 | 333,682 | * | * | 44,420 |

* Figures not available.

TABLE 5.

Value in dollars of school slate produced in the United States, 1913-1931.

| Year | United States | Northampton County | Lehigh County |
|------|---------------|--------------------|---------------|
| 1913 | \$51,313 | \$16,984 | \$34,329 |
| 1914 | 35,205 | 8,308 | 26,897 |
| 1915 | 38,167 | 12,366 | 25,861 |
| 1916 | 52,561 | 19,066 | 33,495 |
| 1917 | 48,828 | 20,816 | 28,012 |
| 1918 | 17,016 | 10,063 | 6,953 |
| 1919 | 54,635 | 22,643 | 31,992 |
| 1920 | 82,989 | 20,240 | 62,749 |
| 1921 | 56,170 | 13,579 | 42,591 |
| 1922 | 42,027 | 11,922 | 30,105 |
| 1923 | 31,102 | 10,086 | 21,016 |
| 1924 | 27,348 | 3,646 | 23,702 |
| 1925 | 35,818 | 1,254 | 34,564 |
| 1926 | 32,886 | 365 | 32,521 |
| 1927 | 19,998 | 741 | 19,257 |
| 1928 | 22,591 | None | 22,591 |
| 1929 | 20,371 | None | 20,371 |
| 1930 | 19,230 | None | 19,230 |
| 1931 | 16,237 | None | 16,237 |

Minor products. Of lesser products there are several that deserve mention. The annual production of billiard table tops in the United States averages \$75,000, of which approximately 75 per cent comes from Pennsylvania in the average year. In Pennsylvania one company is manufacturing marbleized slate.

Several grinding plants for making powdered slate and granules have been established both in the Peach Bottom and Lehigh-Northampton districts, the value of their products in recent years averaging about \$325,000 annually. In 1929 and 1930 the product has been chiefly blue-gray slate; at intervals, however, plants also operated in the red clay-slates of Berks County.

Remarks. For the notable increase in slate production and consumption in the United States during recent years, credit should be given at least in part to the recent organizations of slate producers. There are at least three such organizations,—the Structural Slate Company, the Vendor Slate Company, and the Natural Slate Black-board Company, which with the National Slate Association and the

Committee on Slate of the American Society for Testing Materials, have helped standardize and advertise slate products. This work is of the highest value to producer and consumer alike.

ADAMS COUNTY

General description. The geology and mineral deposits of Adams County have recently been described by Stose, who mentions the occurrence of slate in several localities.¹ These were visited and restudied by the writer with special attention to the possibility of developing quarries, and a brief description follows. None is of economic promise at present.

The region in which the slates are found is a gently mountainous country with a maximum relief of about 500 feet, and chiefly timbered or only under poor cultivation. The slates occur among highly altered volcanic rocks of pre-Cambrian age and in beds in the superjacent quartzites, conglomerates and slates of the Cambrian. Still higher in the sequence are Paleozoic limestones and Triassic sediments and volcanics, but no slate is found in these higher formations.

Mount Hope locality. Half a mile east of Mount Hope on the Fairfield sheet of the Topographic Atlas of the United States Geological Survey, between the highway and one of the headwaters of Middle Creek is a tunnel trending N.35°W. and 75 feet long. This was opened to prospect for "slate" in a highly compressed and schistose fragmental volcanic rock best described as a tuff. The rock shows cleavage having a remarkably uniform strike and dip (strike N.50°E., dip 35°S.), but it is soft and upon weathering changes to a chalky or talcose, massive rock which could not be used in large slabs on account of its softness, low tensile strength, and imperfect cleavage. In color it is olive gray to olive green, approximately 25^d or 35^d of the color chart of the National Research Council, but some pieces upon weathering assume a slightly pinkish tone, evidently through oxidation of iron. The luster is high, suggesting that of massive talc. Under the microscope the dominant minerals are seen to be quartz and muscovite, with some chlorite and rare large grains suggestive of zircon; much limonite is also visible. In thin section the cleavage proves to be poorly developed and irregular.

This rock is not a true slate but rather a schist; it might find utilization in the crushed form as roofing granules, but the irregular cleavage, the tendency to soften on weathering, and the marked rusting all make it unsuited for use in large slabs in roofing.

Mountain Creek locality. Several small prospect pits have been opened in Cambrian rocks about six miles northwest of Bridgeport on the road from Gettysburg to Shippensburg. Other pits and a small outcrop also in the Cambrian, are seen in the same region but half a mile east of the highway, in the valley of Mountain Creek. These openings were evidently not worked with success. Prospecting must have antedated the beginning of the current century. Some of the rock is a slaty conglomerate, but other beds are true slate, verging on schist, and possess fair slaty cleavage, though the latter is gen-

¹ Stose, G. W., Mineral resources of Adams County, Pa.: Pa. Geol. Survey, Bull. C-1, Pt. II, pp. 34-36, 1925; C-1, pp. 124-126, 1932.

erally too irregular to make a good slate. Purplish gray colors predominate, with occasional greenish blotches.

In this region the rock showing the best cleavage was found in a small pit just west of the main Gettysburg-Shippensburg highway. It is an outcrop of slaty Cambrian phyllite of a dark gray color with a faintly greenish or deep purplish tone; it is near 15⁷o or 21⁴e in shade. The cleavage is fair, taken in the large, but slightly irregular and wavy in detail. Texture is uniformly fine-grained. The chief constituents are muscovite, greenish chlorite, secondary quartz, and magnetite,—the latter largely altered to limonite; the two iron oxides together make up nearly 30 per cent of the rock. There is also some primary quartz, usually in poorly rounded grains bearing tiny inclusions, but the dominant sediment originally making up this rock would seem to have been clay. The imperfect cleavage and lack of uniform texture preclude the use of this rock for most purposes for which the better grades of slate are ordinarily in demand.

Wenksville locality. A quarry, on the south slope of Piney Mountain, halfway between Boyd School and Wenksville and just north of the road connecting these two places, was formerly worked for slate. These beds are of Cambrian age. The cut, which is about 200 feet long, exposes approximately 30 feet of slate below, and some 20 feet of white, quartzitic slate, weathering to a light gray, above. The bedding appears to strike N.30°E. with a dip of 40° or more N., the cleavage striking parallel but dipping 45° S.; the structure is inferred to be the upper limb of a northward-overturned anticline. In detail there are many small, close folds; several faults having displacements up to 6 inches are beautifully displayed in the more closely laminated strata (see Figures 37, 38).

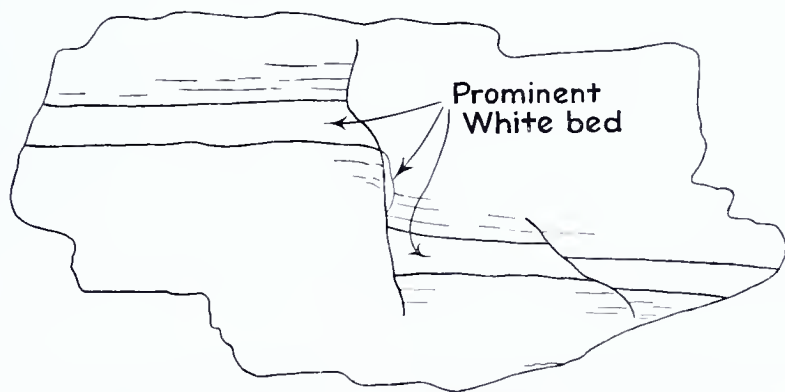


Fig. 37. Faults in banded gray slate, Wenksville locality, Adams County.

At this locality it was the lower, less quartzitic layers, which were formerly worked for slate. They consist of pinkish-gray, violet-gray, or light blue-gray beds of clay slate, not sufficiently metamorphosed to have wholly lost the kaolin-like odor characteristic of shale. On the National Research Council's color chart the corresponding colors are approximately 1⁵d, 1⁴d, or 21⁴e, depending on whether the lilac, pink, or blue gray shade is referred to. Thin laminae of lighter values of the same colors appear as narrow bands generally a six-

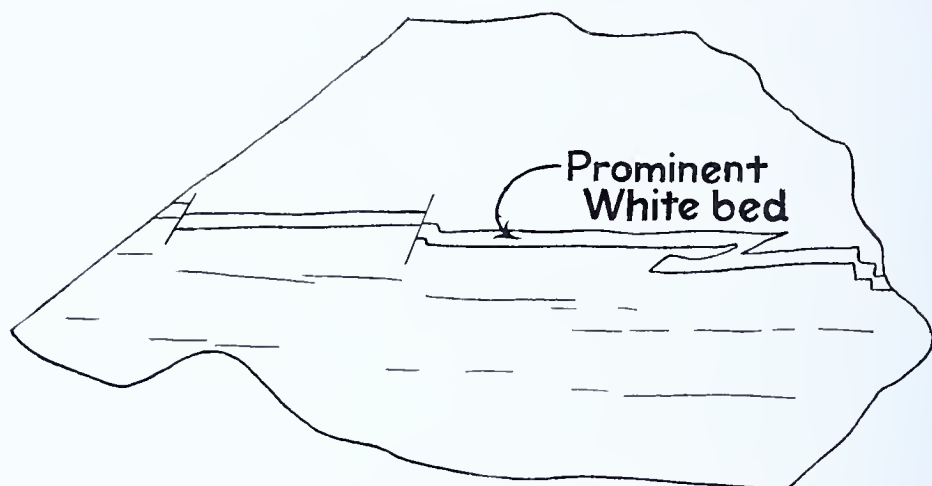


Fig. 38. Faults in banded gray slate, Wenskville locality, Adams County.

teenth of an inch, but occasionally up to half an inch in thickness; these are more prominent in the higher beds. The slate in some places breaks parallel to these laminations, but as a rule the cleavage, though not absolutely plane in detail, is regular and cuts cleanly across the bedding; it is only seldom deflected where it crosses beds of changing composition. Upon weathering the slate separates along the cleavage planes and finally breaks down into a talcose powder; little or no rusting or bleaching marks the progress of weathering along joints or seams, however.

Under the microscope, as at the outcrop, this rock is seen to be of two wholly different kinds. One represents the upper, more quartzitic member,—essentially a fissile clay-slate, somewhat coarse-grained for a true slate; this generally shows very thin kaolin bands that are faintly stained with limonite and that alternate with broader laminae consisting of muscovite and occasional quartz grains. Strangely enough, the rock breaks best parallel to the banding, yet the mica flakes are elongated essentially at right angles to the bands, though the individual crystals are considerably bent and crumpled.

The second kind of rock represented at this locality is the lower, more truly slaty member. This consists of fine needles of white mica, generally well oriented, with occasional subangular pieces of quartz, usually less than 0.10 mm. in diameter. There are also irregular particles of magnetite, of which a few grains exceed 0.15 mm. in diameter but the average is much less, and cloudy, well disseminated areas of hematite. Some of the black matter is probably graphite. The other mineral constituents are occasional irregular areas of secondary quartz and a few small lenses of chlorite. Individual strata differ chiefly in the percentage of darker minerals, in the ratio of coarse-grained minerals (especially quartz) to fine-grained muscovite, and in the amount of feldspar, which, in subangular grains, is frequently an important constituent. Some of the laminae approach arkose in composition, with a corresponding loss of cleavage.

The slate from this locality¹ was once quarried to line the furnace of the Pine Grove Mining Company at Pine Grove Furnace, but for

¹ Stose, G. W., *op. cit.*, pp. 34-35, 1925.

this purpose the arkosic upper member was preferred. Some was also used for clay in brick-making at the same furnace. It might perhaps be crushed for roofing granules, but it is neither sufficiently compacted nor converted to the chemically resistant mica by metamorphism to make an ideal material for this purpose.

CARBON COUNTY DISTRICT

LOCATION OF THE DISTRICT

Although it is possible that usable slate occurs elsewhere in Carbon County, there is only one region where it is known to outcrop and to have been successfully quarried. Even in this locality operations have been discontinued for some time and there is no promise of early resumption. As a reserve, however, this slate belt merits some consideration.

The slate-yielding section of Carbon County is a narrow area beginning at Aquashicola. This village is situated about one and one-half miles north of the crest of Blue Mountain, and an equal distance east of Lehigh River; it is on the eastern border of the larger town of Palmerton, a manufacturing center. Upstream and downstream there are other towns of similar size, but eastward for fifteen miles there are no large communities and the occupation is farming. Two miles to the south of Aquashicola is the northern edge of the slate belt of Lehigh and Northampton counties.

The section studied includes only the immediate region where usable slate is known to occur, and the bordering area. The base map used is a part of the Manch Chunk sheet of the Topographic Atlas of the United States, appropriately enlarged.

This slate belt is readily accessible to the Lehigh Valley, Lehigh & New England, and Central of New Jersey Railroads, but spurs would have to be built from Lehigh Gap northeastward or from the spur tracks in Palmerton. An idea as to track distribution can be gained from the topographic base, which, though prepared some years ago, is still nearly correct.

PHYSIOGRAPHIC FEATURES

To the south of and parallel to the slate belt of Carbon County is the crest of Blue Mountain, a continuous ridge rising to about 1,480 feet and extending northeastward. From this crest northwestward the surface declines to about 420 feet in the wide-bottomed valley occupied by Aquashicola Creek; the latter flows southwestward parallel to the "grain" of the country. Farther northwest is a series of elongate hills suggesting, when the gaps between them are ignored, a northeast-trending ridge with an altitude of 600 to 850 feet. Still farther northwest is another valley that is occupied by a southwest-flowing stream and beyond this another more or less dissected ridge having an elevation of about 900 feet.

It can be shown that these parallel northeast-trending ridges and valleys reflect differences in resistance to erosion by rocks having a generally northeasterly strike. As might be expected, the ridges are underlain by well-indurated, difficultly abraded formations,—chiefly



A. Bray Quarry No. 1, near Aquashicola, Carbon County district.
Smooth face on farther side is cleavage plane.



B. Typical sandy phase of upper part of Hamilton-Marcellus group,
one mile north of Aquashicola.

quartzites, sandstones, and conglomerates; the valleys, on the other hand, are developed in shale and slate, and the slate belt here described is clearly reflected in the more northerly of the two valleys mentioned above.

GENERAL GEOLOGY

Stratigraphy. The rocks composing the sequence in the slate belt are all of Devonian age. The names, lithology, and relative thicknesses of the various formations are graphically shown in Figure 39. The formations in this region were discussed in detail in several reports of the Second Pennsylvania Survey and more recently were briefly described by Agthe and Dynan¹ and again by Miller².

The lowest rock studied is the Oriskany sandstone of Lower Devonian age.³ This is approximately 150 feet thick. It is chiefly a hard, pure, generally white quartz sandstone, with rounded quartz pebbles or grains; in some places it is sufficiently indurated to be regarded as a conglomerate, and elsewhere has suffered so much disintegration as to be virtually a sand which can be dug out with a shovel; this is used for building and for glass-making.

Composing a total thickness of about 35 feet above the Oriskany sandstone are thin beds of clay, limestone, and iron carbonate; generally these are not well exposed here, but careful study by Miller, Agthe and Dynan, and others, has shown that they consist of approximately 4 to 10 feet of plastic clay of white, yellow, red, or blue colors; this is overlain by 2 to 4 feet of impure siderite, blue when fresh and red when weathered, which has been mined for iron ore and pigment. Above the iron ore are about 25 feet of blue-gray shaly limestone, locally used as cement rock. Taken together, these beds seem to represent the Onondagan of New York: they are thus lower Middle Devonian in age.

Above these rocks are shales and slates and shaly sandstones, the thickness of which has been variously estimated as being from 800 to 2,500 feet; from rough measurements it appears to be about 2,000 feet in the slate belt. These are the Marcellus and Hamilton of earlier writers.⁵ In this immediate vicinity the two formations, taken together, may be broken up into two lithologically differing units. The lower of these is dominantly argillaceous in character, and consists of blue-gray slate which weathers to a faintly brownish color. It is in these beds that the slate has been quarried. Cleavage in some localities is so well developed that even the fossils show corresponding distortions (see Fig. 41). Locally, especially in the slate quarries, there is a faint suggestion of banding, the separate laminae being approximately half an inch thick. The upper half of the Marcellus-Hamilton group is more sandy, shows no slaty cleavage, and is a blue-gray to brownish-gray sandy shale.

A bed of fossiliferous shaly limestone, 35 feet thick, the correlative of the Tully of New York, has been described as separating the upper Marcellus-Hamilton from the superjacent, less well indurated shales and sandstones of the Genesee—Chemung group.⁶ This limestone is not exposed in the slate belt, the next rock seen in place being the dark shales of the Genesee and the shaly, olive to buff, locally calcareous sandstones of the Chemung group. These together are esti-

¹ Agthe, F. T., and Dynan, J. L., Paint-ore deposits near Lehigh Gap, Pennsylvania: U. S. Geol. Survey Bull. 430, pp. 445-447, 1909.

² Miller, B. L., The mineral pigments of Pennsylvania: Pa. Top. and Geol. Survey Comm. Report No. 4, pp. 53-56, 1911.

³ Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. Am. Bull., vol. 22, Plate 28, 1911.

⁴ Agthe, F. T., and Dynan, J. L., op. cit., p. 416, 1909; Miller, B. L., op. cit., p. 55, 1911.

⁵ Lesley, J. P., Summary description of the geology of Pennsylvania: Second Geol. Survey Pennsylvania Final Report, vol. II, pp. 1203-1211, pp. 1247-1254, 1892.

⁶ Lesley, J. P., op. cit., pp. 1317-1318, 1892.

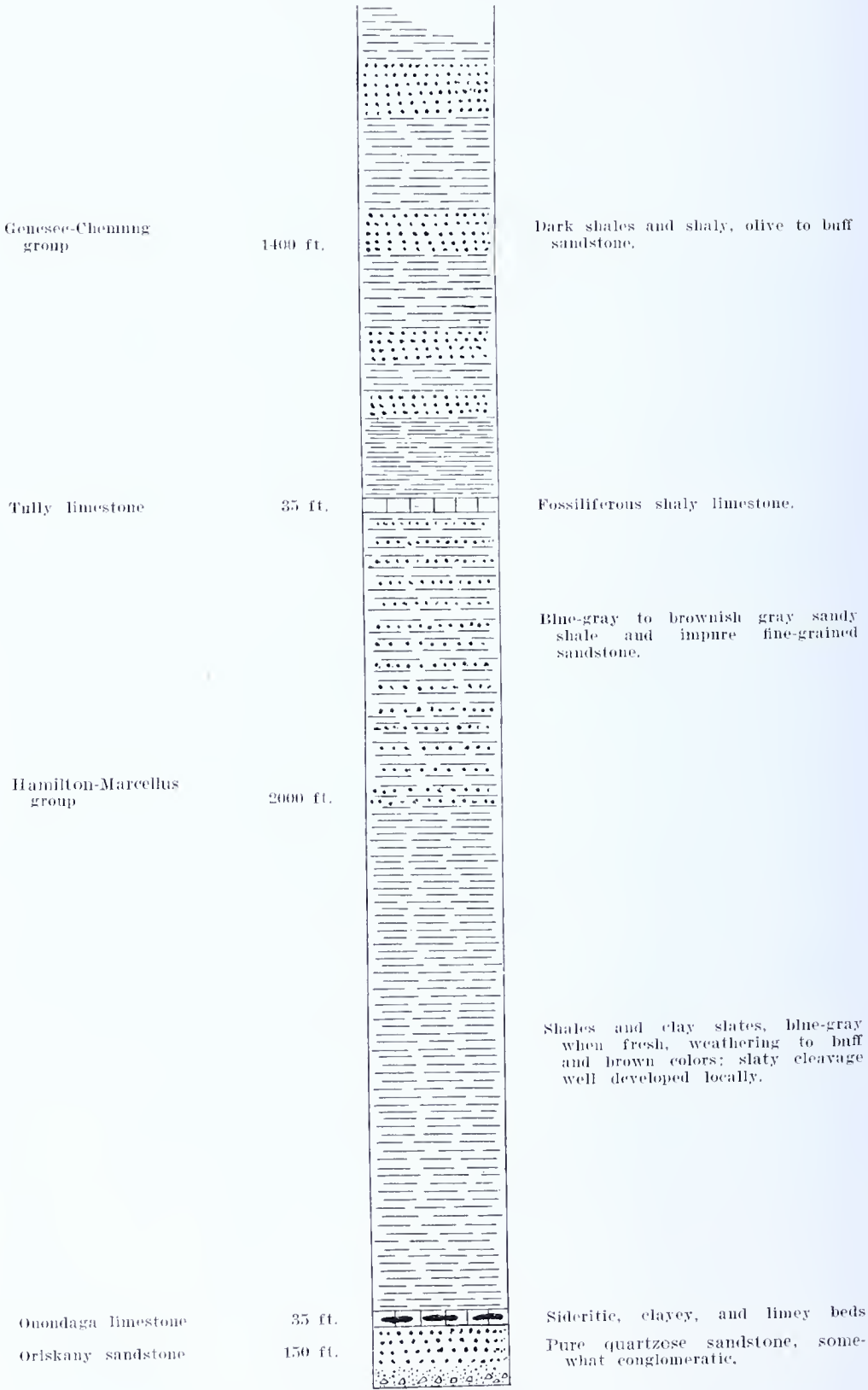


Fig. 39. Columnar section of rocks in Carbon County slate district.

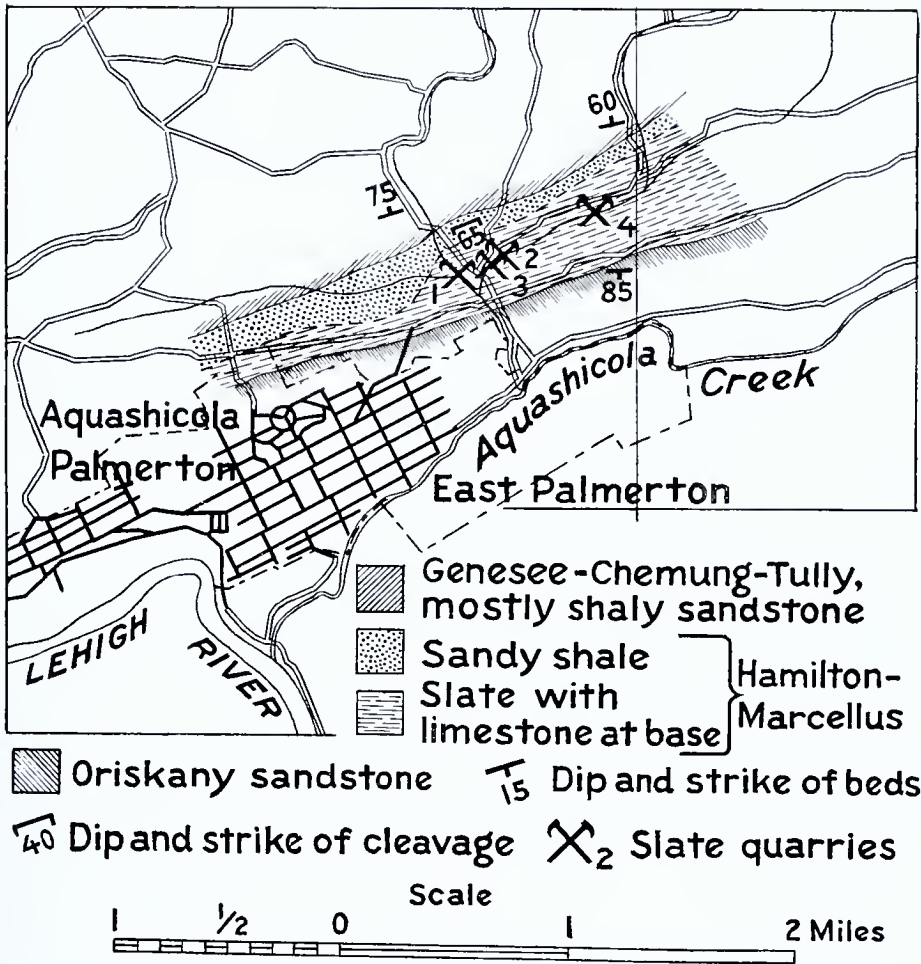


Fig. 40. Geologic map Carbon County slate district.

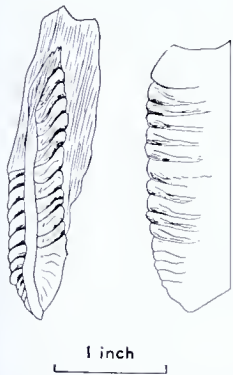


Fig. 41. Two views of a trilobite (*Phacops* sp.) from Carbon County slate district, distorted by the compression which developed cleavage.

mated to be 1,400 feet thick on the Lehigh River. In age they represent the upper part of the Upper Devonian. Lithologically they are distinguished from the subjacent Marcellus-Hamilton rocks chiefly by the greater quantity of sand which they contain. Neither they, nor any of the other formations above the Hamilton were studied in detail, the field traverses being discontinued when these upper formations had been reached.

Structure. As far as can be ascertained from the limited exposures, the structure of the slate belt is very simple, representing the south limb of a syncline. The strike is northeasterly, averaging about $N.75^{\circ}E.$, and the dip steeply north, varying from 70° to 85° . Two miles west of the western edge of the slate belt, as mapped, there is a sharp fold and parallel faulting, and these structures have the effect of repeating the Oriskany sandstone so that it is crossed three times in a northward

traverse along Lehigh River between Hazard and Bowmanstown;¹ there is no evidence of the continuation of this feature eastward into the slate belt proper, however.

Among the lesser structural features, cleavage is, in connection with slate production, of greatest importance. In strike it roughly parallels the bedding wherever cleavage is developed,—clear evidence that the major fold of which this synclinal limb is a part does not possess a noteworthy pitch. The development of cleavage is confined to the lower part of the Marcellus-Hamilton group; in the higher beds the dominantly sandy nature of the sediments precluded its development. Where present it is generally plane and regular, and it nowhere shows the curvature so commonly exhibited by the Ordovician slates south of Blue Mountain.

Jointing was not studied in detail. In one of the large quarries much jointing was seen to strike parallel with bedding and cleavage, dipping vertically. Grain was nowhere observed.

Petrography of the slate. The slate is blue-gray, of approximately the same color as the Lehigh-Northampton district “soft” slate. Megascopically it frequently shows faint lamination, the bands being due to slight variations in carbon content and generally not exceeding 2 (in rare cases, 4) inches in thickness. They weather slowly, the entire slate becoming faintly brownish on long exposure, and losing its original blue-gray colors; the change seems uniform. Characteristic features are occasional lenses or spherical masses of calcareous matter (see Plate 3, A) evidently rich in siderite, which on weathering change to a rusty brown. Cleavage is smooth and regular and becomes irregular and of a papery thinness only after prolonged weathering.

Under the microscope the slate is composed dominantly of sericite and bears in addition large proportions of carbonate (siderite or ferruginous calcite), chlorite, and quartz, named in the order of descending importance. Pyrite, carbon and a little magnetite are the dominant dark minerals, the former two generally occurring in spherulitic masses or in aggregates of such spherulites. Chlorite or carbonate surrounds some patches of the dark minerals. Lenticular or rhombic masses of carbonate have crowded the foliae of sericite aside in some places. Rutile needles are lacking in the slides examined, though the mineral is reported by Dale.² The slate shows considerable darkening in color parallel to certain cleavage planes.

The rounded carbonate “knots” are seen to consist dominantly of calcite or ferruginous calcite and exhibit much rusting which is visible, even under the microscope, as a yellowish coloration.

DETAILED QUARRY DESCRIPTIONS

General description. The slate quarries near Aquashicola are four in number. As all are full of water, the working face is not accessible and geological data are correspondingly meager. None are being worked at present, there is no reason to anticipate an early resumption

¹ Agthe, F. T., and Dynan, J. L., Paint-ore deposits near Lehigh Gap, Pennsylvania: U. S. Geol. Survey Bull. 430, pp. 442-444, 1909.

² Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, p. 109, 1914.

of quarrying, and detailed information as to former operations is not available.

The general description of the structure and composition of the slate is based upon observations in these quarries and hence needs no repetition. In those cases where the rock was seen in place the beds dipped north and the cleavage south at steep angles. Grain direction could not be ascertained and no detailed observations could be made on joints. The quarries are numbered as in Figure 40.

1. *Davies Quarry*. This irregular opening, measuring about 100 feet square, is situated approximately a quarter of a mile north of Aquashicola village, on the west side of the highway that runs northward from the town. It is filled with water and shows a small dump to the south. The slate on the dump is faintly banded; upon close examination these bands prove to be beds slightly more siliceous than the remainder of the rock. The color is the usual blue-gray, but upon prolonged weathering there is a tendency to "rust", the blocks on the dump being yellowish-brown. Cleavage is good when the slate is fresh, but the surface flakes irregularly on prolonged exposure.

Judged by appearances this quarry has long been idle.

2. *Bray Quarry No. 1*. This large opening is about 1,000 feet northeast of the last and south of a northeast-leading road. It is roughly rectangular and measures about 200 feet in a northwest direction by 275 feet. Some 35 feet of slate are exposed above the surface of the water which covers the quarry bottom. The depth is uncertain.

Five feet of weathered slate form the overburden. Cleavage strikes N.87°E., and dips 76°S.; it is regular, but there is a suggestion locally of fracture cleavage, which could, however, not be studied at close range. The beds seem to strike N.78°E., and to dip about 85°N. Heavily mullioned joints strike N.83°E., dip 82°S.

Examined in detail, the slate rings well and shows good, plane cleavage but in many pieces on the dump exhibits joint-like fractures that cross the cleavage surface. The rock is faintly banded, but none of the bands exceed 4 inches in thickness and weathering does not generally accentuate the markings. Some bands, however, are indicated even at first glance by brown "knots" which are further emphasized upon weathering. Individual strata show cross-bedding.

This and quarry No. 3 are on the Craig and Wentz estates. They were last leased and operated by W. M. Bray about 1915.²

3. *Bray Quarry No. 2*. This opening, about 180 feet west of and along the strike from Bray Quarry No. 1, is a small, nearly circular hole about 80 feet in diameter, with a probable depth of 60 feet. Some 20 feet of slate, capped by 5 feet of overburden consisting of weathered slate, show above water level. A single conspicuous parting, apparently along a bedding plane, strikes N.80°E., dips 83°N. The cleavage strikes N.75°E., dips 70°S. The quarry is said to have been operated simultaneously with Bray Quarry No. 1.

4. *Greene Quarry*. This is on the farm of Robert Greene, half a mile northeast of the Bray quarries, in the valley of a tributary of Aquashicola Creek. It is a small triangular opening, each side being approximately 90 feet long. No slate is exposed above the water

² Dale, T. N., and others, Slate in the United States: U. S. Geol. Survey Bull. 586, pp. 108-109, 1914.

level, and that on the dump is similar to the slate from the other quarries described, but shows slightly heavier weathering,—probably due to longer exposure. It was last operated about 1915.

DAUPHIN COUNTY

Dale¹ describes slate obtained in drilling at Derry Church, near Hershey, in the southeastern part of Dauphin County. The locality was not visited, either by Dale or the writer, but the location suggests a stratigraphic position similar to that of the Lebanon County occurrence,—that is, in the lower member of the Martinsburg.

The slate is described as of “dark bluish-gray color, with very fine, even, and somewhat lustrous cleavage surface.” It bears pyrite, in lenses and spherules, is graphitic, and rich in carbonate. Mineralogically it strongly resembles the slate of Lebanon County. Its high quartz content makes it a true “hard” slate.

LEBANON COUNTY

General description. The work of the Second Pennsylvania Survey² has shown that the Martinsburg formation extends westward from Berks County across the Schuylkill into Lebanon County. Here no detailed mapping has been done, but for reasons developed in discussing the geology of the Lehigh-Northampton slate belt it seems probable that the Martinsburg consists only of the lower two of the three members recognized in Berks County and farther east. The lowest member locally contains beds of slate that have been worked with profit from time to time. Only one of these occurrences was actually studied in the field, however (see page 127).

Colored slates. Of possible economic interest also are the red and green slates of the middle member of the Martinsburg, which appear in various places. Thus on the Hummelstown quadrangle, northwest of Annville, there is red shale about one mile east of Syner and again on the road along the east bank of Quittapahilla Creek about two miles southeast of that hamlet. Red shale also occurs a mile south of Union Waterworks, on the same quadrangle and this belt evidently continues westward, for it reappears about four miles upstream on the east bank of Swatara Creek above Manadaville. Other occurrences have been observed on the Lebanon quadrangle; thus, red shale outcrops 1½ miles north of Ebenezer on the road to Bunker Hill, and in several places between Bunker Hill and Lebanon on the east road between these two towns. The relatively long hauls from these localities to railroads would be a serious hindrance in development.

Roofing slate. For the greater part of the distance from Annville to Derry on the Hummelstown quadrangle, a road runs parallel to and roughly half a mile north of the Reading Railroad. At a point on this road approximately three-quarters of the way from Annville to Derry a northward leading road leaves the Annville-Derry road to cross Swatara Creek. Here, on the farm of Mr. J. Elmer Long, is an outcrop of blue-gray, banded slate, with occasional sandy or cal-

¹ Dale, T. N., *Slate in the United States*; U. S. Geol. Survey Bull. 586, p. 109, 1914.

² Lesley, J. P., *Geological hand atlas of Pennsylvania*; Pennsylvania Second Geol. Survey, Report of Progress X, p. LXVIII, plate 22, 1885.

careous layers up to half an inch thick. In general appearance it suggests the "hard", rather than the "soft" slate of the Lehigh-Northampton belt; this is consistent with its areal occurrence and its probably low position in the Martinsburg formation. Unfortunately the more siliceous layers in the slate are so impure that any single cleavage plane seldom crosses the sandy "ribbons." Indeed those blocks that were examined showed one surface developed along a cleavage plane but the other on a bedding plane; as the two planes converge gently, a wedge-shaped block, that is, one tapering down in thickness from end to end, is produced.

A hole filled with water, now 25 feet in diameter, marks the site of the old quarry, long abandoned. In a part of its wall bedding and cleavage are virtually parallel, the strike of both being about N.70°-85°E., with dips of approximately 50°S. The slate quarried shows excellent cleavage, "rings" well, and weathers evenly, with only a slight change in color in the direction of a very faint rusting. Where the more siliceous beds are intersected, difficulty is encountered in getting pieces of constant thickness, as already mentioned. Under the microscope the rock is seen to be uniformly fine-grained. It is very rich in muscovite, and also in calcite in the form of lenticular masses between the muscovite fibres; the calcite is frequently almost rhombohedral in outline, strongly suggesting a secondary origin. In general there is a lack of dark constituents, but graphite and pyrite both occur in small spherical masses; as usual, rutile needles abound.

Although this slate might be worked under exceptionally favorable circumstances, its tendency to wedge out on splitting and the general difficulties in selling "hard" slate would make development unwise under existing conditions. It has already found occasional use for flagstones.

LEHIGH-NORTHAMPTON DISTRICT

LOCATION AND COMMERCIAL SETTING

The slate belt of eastern Pennsylvania. By far the most conspicuous of the Pennsylvania slate districts, both in geographic size and in importance of products is that extending from the New Jersey line at the Delaware Water Gap westward almost to the Schuylkill. This covers part of three counties in east-central Pennsylvania, Northampton, Lehigh, and Berks. The most important development is in Northampton and Lehigh counties; hence this district is here referred to as the Lehigh-Northampton slate district.

Most of the producing quarries are grouped near two general centers. One of these is the area surrounding the towns of Pen Argyl and Bangor, in the northeastern part of Northampton County; this has been fully described in an earlier report,¹ but will be considered again here. The other is at Slatington in Lehigh County. Although workable slate is known to occur between these two regions, there is so little development from Wind Gap (Northampton County) westward to Danielsville that an arbitrary north-south line may logically be drawn approximately midway between the two centers mentioned, that is, along the meridian of 75°30'W. long., separating the district into two parts.

¹ Behre, C. H., Jr., Slate in Northampton County, Pennsylvania: Pa. Top. and Geol. Survey, Bull. M-9, 1927.

The eastern of these two parts lies wholly in Northampton County and is shown on sections of the Delaware Water Gap, Wind Gap, and Allentown quadrangles of the Topographie Atlas of the United States, prepared by the United States Geological Survey. The western part of the slate belt stretches from Danielsville in Northampton County southwestward across parts of the Mauch Chunk, Slatington, and Hamburg quadrangles of the Topographie Atlas of the United States. Taken together these two parts thus form a strip extending in a generally N.60°E. direction for about 50 miles with an average width of approximately 10 miles. The northeast and southwest boundaries are respectively the Delaware and Schuylkill rivers.

The northwest boundary of the area studied is formed by the crest of Blue Mountain, but the southeastern edge is less well marked; it follows the contact of the slate beds with the subjacent limestone layers, mapping having been discontinued when the limestone layers that outcrop to the south of the slate belt had been reached.

Cities and towns. This district is about 65 miles north of Philadelphia, and approximately 95 miles west of New York City. Within it there are seven larger towns,—Portland, Bangor, Pen Argyl, Wind Gap, Walnutport, Slatington, and Hamburg. Of these, Bangor (population 5824 in 1930), Pen Argyl (4310), and Slatington (4134) dominate the industry. Several smaller settlements, chiefly trading centers for the surrounding farms, are distributed through the region. Along the southern border of the slate belt are several towns,—Belvidere (New Jersey), Nazareth, Bath, Northampton, Egypt, Fogelsville, and Kutztown; in these the quarrying of limestone and the manufacture of cement are the leading industries. Six or eight miles south of the slate belt are the four industrial centers,—Easton (population 34,468), Bethlehem (57,892), Allentown (92,563) and Reading (111,171), each providing a near by market.

Until recently the chief occupation in the slate belt, except for agriculture, was quarrying, and the towns mentioned sprang up largely in response to the growth of the slate industry. Within the last two decades, however, a period of decline has set in and it is the manufacture of textiles that is now the basis of growth of the towns in the region.

Transportation facilities. Main lines of several railroads operate along the three large rivers that drain the slate belt. The Pennsylvania and the Delaware, Lackawanna, & Western follow the Delaware River from Manunka Chunk, on the New Jersey side, northward toward Scranton; on the Lehigh, the Central of New Jersey and the Lehigh Valley railroads connect Walnutport and Slatington with Wilkes-Barre to the north and Allentown to the south; the Schuylkill is followed by the Reading and the Pennsylvania railroads. The Lehigh & New England runs parallel to Blue Mountain, from Slatington to Wind Gap, being thus of great use to the slate industry at Danielsville. A branch of the Reading Railway connects Slatington with Reading; this is of special importance to slate producers at Slatedale.

Electric cars and automobile buses connect Slatington with Slatedale, Walnutport and Danielsville. Others link Belfast, Wind Gap, Bangor, Pen Argyl, and Portland.

Where there are no railroads, electric lines, or highways, access is afforded over dirt and gravel roads. Nevertheless in any parts of the district that yield or hold much hope of production, road haulage to a railroad need not exceed four miles.

In recent years the rivers have not been used to a noteworthy extent for transporting slate: they would serve only for handling large shipments.

PHYSIOGRAPHIC FEATURES

General aspects. Physiographically the region is divisible into three parts, the general relief and topography of which is determined in large part by the way in which the underlying rocks resist weathering. These major divisions are the Blue Mountain (underlain by resistant sandstone and quartzite), the slate terrace or slate belt (of which the subjacent rocks are slate and shale), and the limestone valley (underlain by soluble and readily eroded calcareous rocks). Beginning with Blue Mountain at the north, these three divisions form successive steps downward from maximum altitudes of 1,665 feet on Blue Mountain to minima of about 350 feet in the limestone valley.

The chief streams cross the region in a southeastward course, each flowing through a prominent gap in Blue Mountains. Delaware River is a natural boundary for the district on its eastern edge, as Schuylkill River is on the western; midway between the two is Lehigh River. The tributaries of these rivers nowhere cross Blue Mountain, but, heading on its south flank or in the slate belt itself, flow generally southward in irregular courses until they leave the slate, after which they wind across the country over irregular courses to unite with the three major streams.

Blue Mountain. The southern edge of the abrupt slope that rises to the top of Blue Mountain is the northern boundary of the slate belt. Northward from where this slope begins there is no possibility of quarrying slate economically because the talus or debris from the quartzite of Blue Mountain covers the slate too deeply, if indeed the solid quartzite beds themselves do not actually overlie the slate. Blue Mountain has an altitude that averages about 1,500 feet above the sea, with a width of little more than one mile at the base and of a few hundred feet at the crest. The general effect is that of a remarkably even-topped, narrow ridge. In a few places there are gaps cutting the crest. Proceeding westward from the eastern edge of the district the most noteworthy of these are Delaware Water Gap (altitude about 290 feet), Tott Gap (about 1170 feet), Fox Gap (about 1390 feet), Wind Gap (altitude 981 feet), Smith Gap (altitude 1550 feet), Little Gap (altitude 1109 feet), Lehigh Gap through which Lehigh River flows (altitude about 385 feet), and Lehigh Furnace Gap (altitude 1305 feet); westward from the last there are no marked notches until the Berks County line is reached. Thence the crest still remains generally level to the gap of Schuylkill River, the bottom of which has an elevation of about 400 feet. A few prominences rise above the general level of the ridge as well, the most conspicuous ones being Bake Oven Knob, at 1,565 feet above tide, and the Pinnacle, which is 1625 feet high.

Although this level crest of Blue Mountain preserves a general east-north-east trend, it is not strictly linear. North of Bangor there are two marked sigmoid flexures, of which the easterly is called the Little

Offset, and the other the Big Offset. West of Eckville is the most noteworthy departure from the rectilinear form. Here as the ridge crest is followed it suddenly swings southward, leaving its generally southwesterly trend, and then turns southeastward, so as to give a marked reentrant west of Eckville; at the lowest place in this crescent-shaped mountain form the road leading westward from Eckville crosses. About a mile southeast of this crest-point, the main ridge trend suddenly turns southwestward again so as once more to resume its usual direction, but after two miles with the southwesterly bearing it again swings toward the southeast, giving another marked reentrant, parallel to, but larger than that due west of Eckville. This southeast trend ends at the Pinnacle; thereafter the southwestward direction is resumed and maintained with slight irregularities all the way to the Schuylkill River.

Few roads cross Blue Mountain, and its crest and slopes are virtually uninhabited. Large talus blocks on the sides, a generally sandy soil, and the lack of springs or other permanent sources of water combine to inhibit any farming, even on the smallest scale. The mountain supports little else than isolated conifers and a poor second growth of deciduous trees; in most places this stunted forest is so dense as to be almost impenetrable.

The slate terrace. The slate terrace, though in places as much as twelve miles wide when measured at right angles to its greater dimension, is in reality only a sort of step downward from Blue Mountain to the limestone valley. Its altitude varies from place to place but, taking the relatively level divides alone and ignoring the deeply cut stream valleys between, it is remarkably even topped. Nevertheless, it shows differences when studied in detail. The most striking of these is the generally higher elevations (700, 800, or even 900 feet) attained by individual summits and divides in the middle part of the slate belt. The area with such unusual heights has a trend roughly paralleling that of Blue Mountain and of the limestone valley. As streams cross this belt their generally moderately wide valleys become increasingly steep walled, and miniature canyons with narrow sides result. When the geology is studied, it is seen that this series of higher crests and divides is coextensive with a change in the character of the bed rock; the slate or shale that underlies this physiographic subdivision is far more sandy than elsewhere under the slate terrace. Its less ready erosion evidently is the cause of the topographic prominence of this area.

This is a relatively thinly settled region. The sandy soil is poor in plant foods, and the commonly steep slopes, though not very rugged, are yet sufficiently abrupt to discourage cultivation except near the crests of the wider divides. Hence the farms are not the large and prosperous ones that characterize the limestone district to the south, and in general the nearer to Blue Mountain, the thinner the population, the poorer the homes, the smaller the land plots under cultivation, and the more widely spaced and less well maintained the roads.

The limestone valley. Southeastward from the slate terrace, the observer descends a relatively abrupt slope for some 50 or 60 feet and then finds himself upon a narrower flat varying in width from a quarter to two miles. The country rock here is calcareous but has a

PLATE 26.



A. Escarpment between slate terrace and limestone valley (foreground).



B. Blue Mountain (surmounted by Kittatinny peneplain), with the slate terrace in the foreground.



C. Hilly topography typical of the middle, sandy member of the Martinsburg formation; west of Richmond.

high content of clayey materials; it is the Jacksonburg limestone or "cement rock." Though slightly more elevated than the major part of the limestone valley, this Jacksonburg terrace may well be included with it. The Jacksonburg limestone is not shown as a separate formation on the accompanying maps.

The southern limit of this terrace is marked by a gentle, frequently scarcely recognizable decline in altitude,—the northwestern boundary of the limestone valley proper, underlain by limestone and dolomites that weather and erode more rapidly than the impure "cement rock"; these are the pre-Jacksonburg (Ordovician and Cambrian) limestones. The higher divides on this lowest terrace are generally around 400 or 500 feet above the sea. Between them are gentle slopes and the valleys bear sluggish streams, generally not deeply entrenched, as opposed to the steep-walled, rapidly flowing creeks of the slate terrace. These two types of topography—the slate terrace and the limestone valley—are thus sharply contrasting in appearance.

The limestone valley is the rich farming belt of Northampton, Lehigh, and Berks counties. It is well settled and crossed by numerous roads; farm houses dot the rolling surface and the fields are wholly under cultivation, except where a small town, a cement quarry, or some industrial plant occupies the land.

Terraces and peneplains. The generally broad and flat divides of each of these physiographic subdivisions have encouraged geologists to recognize in each the remnant of a topography resulting most probably from river work so prolonged as to yield a virtually level surface. Such nearly level surfaces of erosion are called peneplains. Perhaps a better term, more consistent with what appears to be their origin here, is "erosion level." After uplift such levels are subjected to renewed dissection by any streams which cross them, and presently only discontinuous remnants remain. Remnants of several erosion levels of this type have been described as the Kittatinny erosion level (marked by the crest of Blue Mountain), the Schooley erosion level (preserved locally as spurs and benches on Blue Mountain), the Harrisburg and related erosion levels (shown generally in the summits and divides of the slate region), and the Lancaster or Somerville erosion level marked in part by the level of the limestone valley.¹

In addition to these broader features many smaller terraces bordering the major streams are clearly related to the history of these rivers. Thus, the Delaware, Lehigh and Schuylkill have several sets of terraces apparently recently formed. One of these is well shown on the east bank of Lehigh River between Walnutport and Treichlers, at an altitude of about 400 feet. It bears river gravel which covers a fairly level slate surface.

GENERAL GEOLOGY

SUMMARY

The outcrop of workable slate beds determined the extent of the area studied. For this reason the greater part of the region mapped is underlain by only one formation,—the Martinsburg slates, clay slates, and sandy shales of the Ordovician period. This outcrop area, how-

¹ Bascom, Florence, *Cycles of erosion in the Piedmont province of Pennsylvania*: Jour. Geol., vol. 29, pp. 540-559, 1921; Knopf, E. B., *Correlation of residual erosion surfaces in the eastern Appalachian Highlands*: Geol. Soc. Am. Bull., vol. 35, pp. 633-668, 1923.

ever, is bordered by older and younger rocks from Cambrian to Silurian in age. Farther south are mountains composed of pre-Cambrian gneisses and schists, and farther north younger strata including the anthracite formations of Pennsylvanian age.

All of these rocks except those of the pre-Cambrian have a generally northwest dip and take part in a large monocline. In many places, however, minor intense folding is superposed upon this north dip in such a way as to complicate greatly the detailed structure. Moreover, there are several major thrusts and some small faults differing in strike, dip, and displacement, which introduce still further variations. In those rocks which, because of composition or by their position with regard to earth stresses, have been induced to recrystallize greatly, slaty cleavage is also well developed, together with other structural features usually related to regional metamorphism.

STRATIGRAPHY

GENERAL STRATIGRAPHIC COLUMN.

An earlier report¹ on the slate belt of the eastern part of Northampton County, Pennsylvania, summarizes what was known up to 1927 as to the stratigraphy of the Martinsburg and the associated formations in eastern Pennsylvania. The normal sequence from the surficial deposits downward in stratigraphic succession is indicated in Figure 42. Of this series the rocks that border the lower margin of the slate-bearing Martinsburg formation are altogether Ordovician and Cambrian limestones and there is no knowledge of any place where the Martinsburg formation comes directly in contact with the Hardyston quartzite, either in the normal sedimentary sequence or through faulting.

CAMBRO-ORDOVICIAN LIMESTONES.

A very detailed description of these limestones was given in an earlier report²; a repetition is not called for, but, because their recognition may furnish a clue to structure on the edges of the slate belt, a few sentences, at least, may be given to each formation.

The Tomstown limestone is a blue-gray, dolomitic limestone in massive beds, with thin, originally shaly, now sericitic layers; black flint is occasionally present. Its lower beds are said to contain a sandy phase grading downward into the Hardyston quartzite. Higher up the formation becomes more argillaceous, or, having been folded, shows thinner sericitic beds due to the alteration of clayey matter. Its thickness is 1000 feet or so. Its age is lower Cambrian.

The Conococheague (Allentown) limestone consists of thick beds of alternating limestones and dolomites, white, cream, buff, or light blue-gray in color, weathering to lighter shades of the same. The massive beds, frequently showing very close jointing and generally characterized by the presence of *Cryptozoon*, are distinctive. Oolites and ripple marks are not rare. Chert and flint nodules are not lacking, but are rarer than in the Tomstown limestone; highly sericitized layers, also, are less generally observed. It is the thickest member of the Cambrian series in the region studied and by far the most commonly seen in the

¹ Behre, C. H., Jr., *Slate in Northampton County, Pennsylvania: Pa. Top. and Geol. Survey Bull.* M-9, pp. 10-43, 1927.

² Behre, C. H., Jr., *op. cit.*, pp. 12-18, 1927.

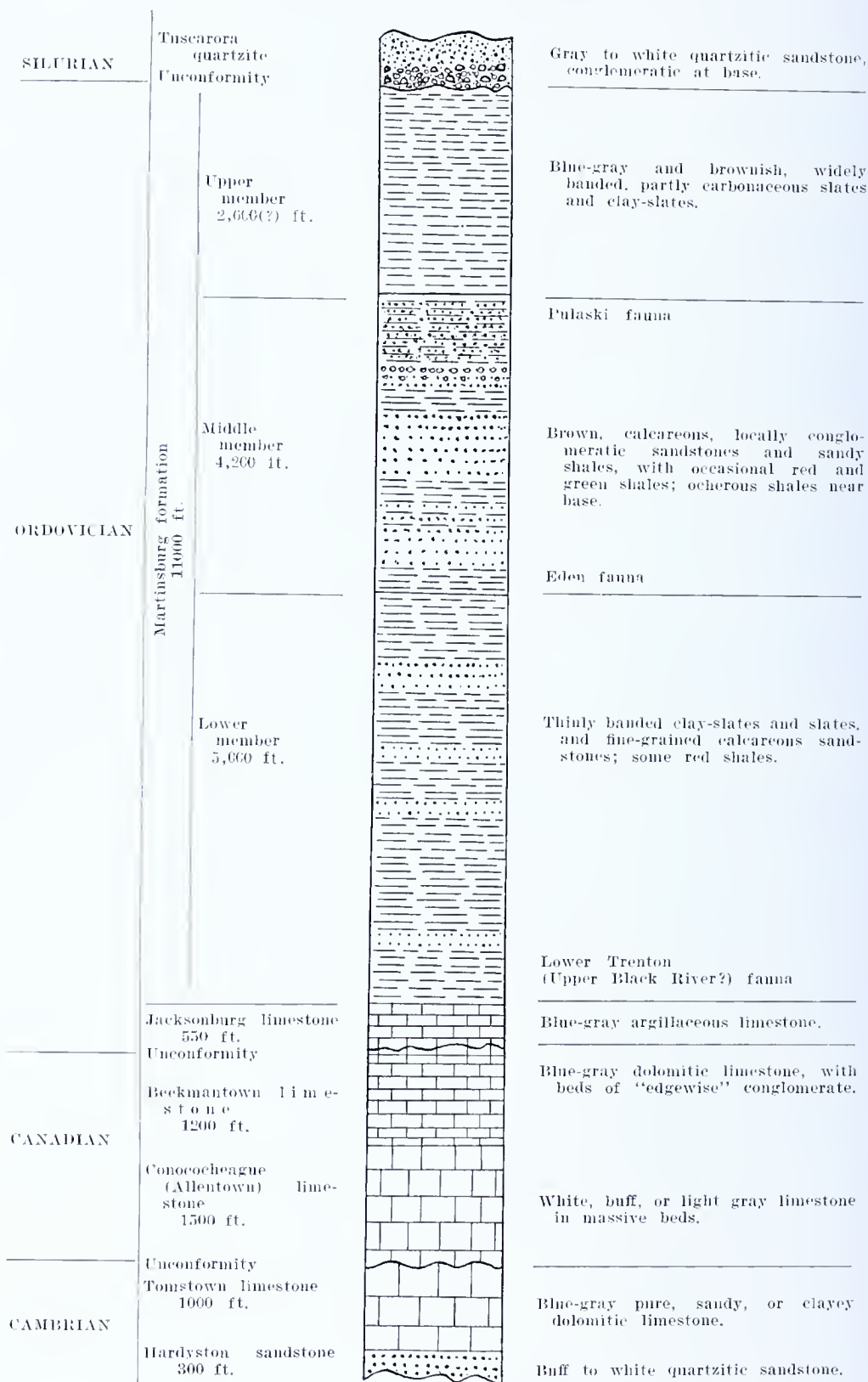


Fig. 42. Stratigraphic column of the Martinsburg and associated formations in eastern Pennsylvania.

none too frequent outcrops. The thickness is about 1500 feet. The age is late Cambrian (Ozarkian, Ulrich).

There is a marked hiatus between the fossiliferous part of the Toms-town, at least in southeastern Pennsylvania, and the Allentown limestone. This hiatus apparently represents middle Cambrian time, during which, in south-central Pennsylvania, the Waynesboro and Elbrook formations or their equivalents were being laid down. A probable disconformity has therefore been suggested by Ulrich, who states that during the middle Cambrian the area from the Harrisburg axis northward remained emerged.

The Beekmantown limestone is a blue-gray dolomitic rock in massive or thin beds, somewhat oolitic in spots. It is distinguished from the Conococheague by the somewhat lower magnesian content and the generally more thin-bedded character. It is more massive below, more thinly bedded above, and becomes progressively leaner in magnesia upward. Edgewise conglomerate, consisting of slender fragments of buff-colored, finely crystalline dolomite, which weathers to a light gray, set in a matrix of dark, occasionally fetid, more coarsely crystalline limestone is seen in some beds. A siliceous "wash", forming on the weathered surface a fine, buff-colored or dark network, is characteristic. These two features are not lacking in the Allentown limestone, and thus are a source of confusion, but the more highly calcareous nature of the Beekmantown serves to distinguish the two lithologically. Its age is lower Ordovician. The thickness is about 1000 to 1500 feet.

The Jacksonburg limestone or "cement rock" shows many different facies. Locally it is quartzitic or more commonly shaly; in the latter case it is dark blue or even black in color. Very probably it is a facies of this rock for which Stose and Jonas have created the special name Leesport limestone¹. The formation has a thickness varying from 250 to 600 feet.² The age is Black River and Trenton.

The dark beds at the top of the Jacksonburg formation and the overlying slate are alike in color, in the hue assumed on weathering, and in the possession of a fairly well developed cleavage. Application of acid, however, distinguishes them at once, as the Jacksonburg limestone effervesces freely.

The sequence is also said to include a limestone of Stones River age³, but the evidence for the age reference is too slender, the exposures are too intermittent, and the structural relations still too imperfectly known to justify the recognition of a separate formation of that age in the area here described.

All of these limestones of pre-Martinsburg age are mapped collectively as Cambro-Ordovician limestones without attempts at differentiation.

Relations between limestones and Martinsburg formation. The relations between the slate and the underlying limestones are generally normal but the appearance of outcrops of limestone resembling the

¹ Stose, G. W., and Jonas, A. L., Ordovician shale and associated lava in southeastern Pennsylvania: Geol. Soc. Am. Bull. vol. 38, p. 509, 1927.

² Miller, B. L., Limestones of Pennsylvania: Pa. Top. and Geol. Survey Bull. M 7, pp. 107-108, 1925; Behre, C. H., Jr., Slate in Northampton County, Pennsylvania: Pa. Top. and Geol. Survey Bull. M 9, pp. 17-18, 1927.

³ Stose, G. W., and Jonas, A. L., op. cit., p. 507.

Tomstown and Conococheague formations locally within the slate belt has led to interpretations of faulting or unconformities in which the upper limestones are thought to have been removed by erosion or never deposited and the slates to rest directly upon the lower limestones¹. An alternative explanation is that these limestone outcrops represent calcareous lenses within the slate formation. The finding of the fossil *Cryptozoon* in some such anomalous limestone masses favors, though it does not conclusively prove, the correctness of the former interpretation. These limestones are here classed with the Martinsburg.

From the Lehigh westward Stose and Jonas² have described areal relations suggesting either local unconformities beneath the Martinsburg, as a result of overlap, or complex faulting. In this region the age of the limestone found just beneath the shale or slate in the various outcrops varies considerably. At Egypt, north of Allentown, it is Ozarkian³, but from Egypt westward the rock immediately below the slate is generally the Leesport limestone of Stose and Jonas, which is the approximate equivalent of the Jacksonburg limestone of earlier reports. Irregular thrust faulting here and there complicates the areal distribution of shales and limestones and frequently aids in bringing pre-Jacksonburg limestones against the Martinsburg formation. As these relations were not studied in detail, there will be no further discussion of pre-Martinsburg stratigraphy, excepting as it bears directly upon the age of the Martinsburg.

THE MARTINSBURG FORMATION.

General description. The area studied for the purpose of this report lies wholly in the northern parts of Northampton and Lehigh counties, and in that part of Berks County east of the Schuylkill. What follows is therefore a description of the Martinsburg formation only as it appears in this section of Pennsylvania.

For practical purposes, the formation is best subdivided on a lithologic basis into a lower, a middle, and an upper part.⁴ The lower part is characteristically a banded clay slate, though there are also thin sandstone beds. The middle member contains sandy beds as its most typical facies, though some truly slaty beds are also found in it. The uppermost member is banded like the lower, but there is less sand and the individual beds are much thicker. The differences between these subdivisions are relative and in areal mapping the line between them is drawn with difficulty.

Judging from his detailed work in southern Pennsylvania and from reconnaissance studies in the region here discussed, Stose has interpreted the Martinsburg as comprising only two distinct members—a lower shaly and an upper sandy one—and regards the uppermost, banded, slaty member of Behre as the lowest member repeated by folding. His viewpoint is well supported by field data, but the difference is chiefly one of structural interpretation and hinges upon evidence not as yet available, so that a final settlement is not possible at present. The structural interpretation of Stose is well set forth in a

¹ Stose, G. W., and Jonas, A. I., Ordovician shale and associated lava in southeastern Pennsylvania: *Geol. Soc. Am. Bull.*, vol. 35, p. 513, 1927.

² *Op. cit.*, p. 512, 1927.

³ Ulrich, E. O., Personal communication; see also Stose and Jonas, *op. cit.*, p. 512.

⁴ Behre, C. H., Jr., Observations on structures in the slates of Northampton County, Pennsylvania: *Jour. Geol.*, vol. 34, pp. 484-487, 1926.

recent publication¹ and that of the writer is given in the maps, structural sections, and local descriptions of this report. Though of scientific interest, the differences in viewpoint are not of much practical importance; further reference is made to them on later pages. If the reader accepts the interpretation of Stose, he should read "lower" where in this report the "uppermost" member of the Martinsburg is referred to.

The exact thickness of the formation is in doubt and there are no places within the region here described where the exposures are sufficiently continuous to yield dependable measurements. Along Delaware River, Sanders estimated the entire Martinsburg to be 5240 feet thick, but says that this "is more likely an understatement than an exaggeration."² This is the maximum thickness mentioned in any of the reports of the Second Geological Survey of Pennsylvania. Stose regards the thickness as about 3000 feet.³ Three sections have been measured in great detail by the writer,—one each along the Delaware and Lehigh rivers and one between the two streams—and the arithmetical average of these measurements is 11,534 feet, though on account of possible repetition through folding, this is probably too high, rather than too low a figure. It is impossible to obtain accurate measurements, yet it would seem that approximations should not be discounted in favor of mere guesses. In general, the thickness in this region may therefore well be taken as about 11,000 feet.

Lower Martinsburg member. The lower member is generally a thin-bedded clay slate or slate. Its prevailing colors are blue-gray or dark silvery gray near the "neutral gray k" of Ridgway's color chart, weathering to light yellowish-brown or buff. It contains layers that are alternately siliceous, sericitic or carbonaceous; the resulting banded character is the distinguishing feature of this part of the formation. This banding is shown on the fresh cleavage surface by streaks that are more silvery where siliceous, and grade more toward a black where carbonaceous. Individual beds are generally two or three inches or less in thickness, and never exceed a foot. Workable slate beds are not found throughout the lower Martinsburg, but occur only at certain horizons. Some good banded slate has been quarried with profit in parts of Northampton County, as at Chapman and near Belfast, but it is not extensively worked out except at the places named. These will be discussed in detail in the individual quarry descriptions.

The lowest part of this member consists along the Schuylkill of a dirty olive-green to grayish-brown micaceous sandstone and sandy shale; this is shown due west of Shoemakersville on the west bank of Schuylkill River in cuts of the Reading Railroad, and again in cuts of the same railroad about a quarter of a mile north of the West Leesport station. Followed eastward the lowest beds become more blue-gray and less shaly and correspondingly more sandy until they are predominantly blue-gray, rusty-weathering, locally calcareous sandstone, as in the hills two miles north of Maxatawny in the Slatington quadrangle. Still farther east, on the Lehigh and Delaware rivers the

¹ Stose, G. W., Unconformity at the base of the Silurian in southeastern Pennsylvania; Geol. Soc. Am. Bull., vol. 41, pp. 629-657, 1930.

² Sanders, R. H., Geology of Lehigh and Northampton Counties; Pennsylvania Second Geol. Survey, D. 3, vol. 1, p. 85, 1883.

³ Op. cit., p. 634.



A. Typical outcrop of middle, sandy member of the Martinsburg formation near Hamburg.



B. Block of typical lower Martinsburg, showing characteristic closely spaced banding.

rock consists of blue-gray sandy shales and sandstones alternating in thin beds. Locally, as near Jamestown and Lebanon¹, there are also some red and green sandy shales, though these are generally more characteristic of the middle member of the Martinsburg. There are also in the lowest member local lenses or beds of limestone up to three feet in thickness. Of these some are almost free from argillaceous matter and consist of layers of light or dark blue-gray limestone, weathering white, buff-colored, or light gray, and suggesting in their dense texture the limestones beneath the Martinsburg, especially some facies of the Allentown. Some of the thinner calcareous inter-beds are well shown along the east bank of Schuylkill River at Mohrsville. As yet they have yielded no fossils.



Fig. 43. Sketch of block of hard slate, showing folding, possibly due to solifluction, previous to the development of cleavage; the surface of the page is parallel with the cleavage. Graber quarry.

In the next higher part of the lowest member of the Martinsburg, the beds are more clayey, shaly, or slaty and are largely sericitized, and it is in these strata that the workable slate occurs. These slaty phases are described in greater detail in the discussion of the "hard" slate. In this member there are also sandy strata, but sericitized, originally clayey layers predominate.

The thickness of this lowest member of the Martinsburg formation in Lehigh and Northampton counties is about 5000 feet. No sections have been measured farther west, but from the width of outcrop it is assumed that this figure also holds for eastern Berks County.

The character of the contact of the Martinsburg with the subjacent formations varies regionally, as already indicated. In some places the shale or slate passes downward gradationally into shaly, impure limestones of the Jacksonburg formation. Elsewhere it rests with unconformity or angular unconformity upon pre-Jacksonburg limestones. In other places, again, the contact is a fault plane. The significance of these relations to Martinsburg stratigraphy lies in determining the age of the earliest Martinsburg beds; what with the rarity of fossils in the Martinsburg, these subjacent limestones furnish the chief clue to the age of the lower Martinsburg. On the Delaware River at Portland the limestone immediately underlying the Martinsburg is of Trenton age, as indicated by its fauna.² At Nazareth, the upper part

¹ Stose, G. W., and Jonas, A. L., op. cit., pp. 526-527, 1927.

² Behre, C. H., Jr., op. cit., p. 17, 1927; this correlation is based especially on the work of Dr. Stuart Weller, cited in the reference given, but also on oral communications with Drs. E. O. Ulrich and Rudolf Ruedemann.

of the limestone is of lower Trenton age.¹ These observations lead to the inference that the Martinsburg formation in eastern Northampton County is of early or middle Trenton age.

Eastward from the Delaware, where the formation has been studied by the writer, the fossils suggest that the shaly phase of middle Ordovician sedimentation appeared slightly earlier than west of Delaware River. At Branchville and Jutland, New Jersey, the fossils collected by Weller are of "Normanskill" age² and may thus well have been laid down in Upper Black River time, though Ulrich regards them as Trenton. In Orange County, New York, fossils in the Martinsburg are said to show a "mixed Hudson River-Trenton" fauna.³

In southern Pennsylvania, near the Maryland line, the Martinsburg passes downward into the Chambersburg limestone through a transition, the "Sinuities zone," of earliest Trenton age, and the fossils of the lower 100 feet of true shale are of lower to middle Trenton age.⁴ If the "Sinuities zone" is included with the Martinsburg, the latter thus begins here with the Trenton.

To summarize the known facts regarding the age of the lowest member of the Martinsburg, it is reasonable to assume that the beginning of the mud deposits that make up the Martinsburg formation was in early Trenton or very late Black River times and, from what will be said below, continued to the Eden (middle Eden?) sub-epoch.

Middle Martinsburg member. The middle member of the Martinsburg formation is generally composed of two types of rock,—(1) blue-gray banded and commonly sandy shales, resembling in general the more sandy layers of the lower Martinsburg and (2) fine to coarse arkosic sandstones, almost always very impure with shale or lime admixture, and locally bearing pebbles which vary in diameter all the way up to one inch. In addition ocher-colored, brick-red, and green shales and sandy shales are present in some parts of the formation, notably in Berks County east of Schuylkill River, where they are being quarried at Lenhartsville and Greenawald. In a few places the shaly beds of the middle Martinsburg have been sufficiently compressed to yield slaty cleavage, but none of the quarries where attempts were made to work this rock as slate is operating at present, and it is not believed to be a promising horizon for slate making under the existing conditions in the industry.

The thickness of this member in the area here discussed is about 4200 feet, this being the average of two measurements—one along Little Bushkill Creek and the other along Lehigh River.

Like the other subdivisions of the Martinsburg formation, this member bears fossils but rarely. The massive calcareous sandstones frequently show traces, yet even in these collecting is very poor. Five collections however, all from approximately the same horizon, show 19 species, said by Ulrich⁵ to be of Pulaski age in terms of the New

¹ Miller, B. L., Mineral pigments of Pennsylvania: Pa. Top. and Geol. Survey, Comm. Rept. No. 4, pp. 15, 19, 1911.

² Weller, Stuart, The Paleozoic faunas: N. J. Geol. Survey Rept. on Paleontology, vol. III, p. 52, 1903; Lewis, J. W., and Kummel, H. B., The geology of New Jersey: New Jersey Geol. Survey Bull. 14, p. 47, 1915; Ruedemann, Rudolf, personal communication.

³ Ries, Heinrich, Geology of Orange County: N. Y. State Museum Ann. Rept., vol. 49, II, p. 441, 1898.

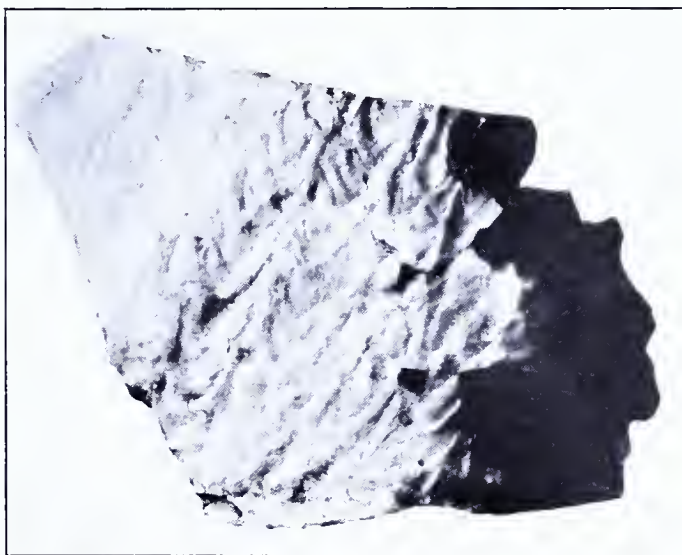
⁴ Stose, G. W., Mercersburg-Chambersburg Folio: U. S. Geol. Survey Geol. Atlas of the U. S., p. 10, 1909.

⁵ Ulrich, E. O., Personal communication, 1927.

PLATE 28.



A. Typical middle Martinsburg sandstone showing fossil tracks.



B. Middle Martinsburg sandstone bearing U-shaped ripple marks indicative of shallow water.

York section or to represent a horizon between McMicken (upper Eden) and Mt. Hope (lower Maysville or lowest Fairview) in the Cincinnati section. As far as the writer is aware, these five collections and some of similar age made by Stose in about the same horizon are

the only available criteria for the age-correlation of the middle Martinsburg east of Schuylkill River in eastern Pennsylvania.

The larger part of the fossils are from coarse, impure sandstone occurring near the top of the middle member. The list, identified by Dr. E. O. Ulrich, includes:

| | |
|--|--|
| <i>Zygospira modesta</i> | <i>Sinuities</i> aff. <i>cancellatus</i> |
| <i>Dalmanella</i> cf. <i>multisepta</i> | <i>Lophospira</i> aff. <i>obliqua</i> |
| <i>Sowerbyella sericea</i> | <i>Tetranota rugosa</i> |
| <i>Hebertella sinuata</i> | <i>Liospira</i> aff. <i>progne</i> |
| <i>Plectorthis</i> cf. <i>plicatella</i> | <i>Lepidocoleus jamesi</i> |
| <i>Rafinesquina</i> aff. <i>camerata</i> | <i>Aparchites</i> (?) sp. |
| <i>R.</i> cf. <i>alternistriata</i> | <i>Ctenobolbina ciliata</i> |
| <i>R. centrilineata</i> (?) | <i>Calymene</i> sp. |
| <i>Strophomena</i> spec. nov. | <i>Proetus</i> sp. |
| <i>Ctenodonta</i> aff. <i>levata</i> | |

At a somewhat lower horizon olive-greenish to ocher-colored, slightly gritty shales bear a few trilobites and brachiopods.¹ This widely distributed but meager fauna has been collected in many places below the overlying Tuscarora from Eckville westward, and is believed by Stose to be an interbed in the lower member of the Martinsburg. In this report, however, the practice has been followed of mapping it with the sandy beds immediately below and the heavy sandstones above it in the middle member. East of the Schuylkill it has yielded fossils at Eckville, on the road leading west over Blue Mountain, at an altitude of 1,100 feet, and at a road intersection half a mile N.20°W. from the church in New Tripoli (Hamburg quadrangle).

A small collection of poorly preserved fossils was made from the sandy beds here mapped as middle Martinsburg, south of Point Phillip (Wind Gap quadrangle), and was referred to E. O. Ulrich, who pronounced them to be older than Pulaski, and probably Trenton in age²; but the reference may well be doubted, in view of the poor state of preservation.

In general, it may be said, therefore, that the middle, sandy member ranges in age from Eden (middle?) to Pulaski. The Eden part Stose would place in his "lower" Martinsburg, reserving his "upper" Martinsburg for the calcareous sandstone known to be of Pulaski age. In this report, on the other hand, the lower line of this subdivision is drawn for practical purposes on a lithologic basis, at the first appearance of prominent sandy beds. The top of the middle Martinsburg is placed above the massive sandstone. The writer interprets the heavy sandstone of Shochary Ridge as an intercalation from the west, probably represented by more shaly layers east of Lehigh River.

On the Hamburg quadrangle, about half a mile east of the railroad station of Greenawald, is a conical mound called Spitzenberg, which rises to the height of 1090 feet. The lower slopes of this mound are underlain by rocks typical of the middle Martinsburg, for peneifracturing, olive-gray slate shows at an altitude of about 940 feet on the western side, and 50 feet lower there are discontinuous exposures of massive, brownish-weathering middle Martinsburg sandstone. Yet the upper 140 feet of this hill furnish an excellent exposure of a coarse, heavily cross-bedded sandstone with interbedded coarse conglomerate. The largest cobbles are 9 inches in diameter. Most of the cobbles are flat, with unequal diameter; generally their long axes are

¹ Stose, G. W., op. cit., pp. 640, 643, 651.

² Stose, G. W., op. cit., p. 655.

inclined to the horizontal and are parallel to the cross-bedding in the sandy matrix, the arrangement suggesting foreset beds in a delta. The cobbles are chiefly limestone; some show close cross-bedding, and lithologically resemble the Beckmantown; most are a dense, dolomitic limestone suggestive of the Conococheague; a few are of a pink, sandy limestone wholly different from other rocks exposed in this region. Rare chips, partly rounded, of red clay-slate are also found and a few still rarer quartz pebbles. The matrix in which these cobbles are imbedded, as well as the interbeds of sandstone, are made up of coarse, greenish gray sand not very different from some facies seen elsewhere in the middle member of the Martinsburg, both megascopically and microscopically; the cement between the sand grains consists largely of calcite, to a minor degree of muscovite; the grains are highly variable as to form, some being well-rounded and others sharply angular; a noticeable quantity of feldspars (both plagioclase and microcline) is present; and the quartz grains show few strain-shadows and do not interlock through secondary growth to any marked degree.

The structure of this immediate region is not easily deciphered. Stose¹ interprets the limestone conglomerate as overlying unconformably the Martinsburg strata that outcrop at lower altitudes. The sandstone and conglomerate at the top of Spitzenberg have an average strike of N.50°E., and dip 8°-12°NW. Several exposures of typical middle Martinsburg rocks on the road and railroad west of Spitzenberg strike similarly (N.65°-70°E.) but dip variously from 50° to 87°SE.; comparable steep southeasterly dips are seen in typical middle Martinsburg sandstone one mile east of Spitzenberg. The limestone conglomerate on the crest of Spitzenberg is thus not accordant with the regional structure. In view of this fact, coupled with its unusual lithologic character, the Spitzenberg conglomerate can only be referred to the middle Martinsburg with serious reservations, a procedure nevertheless followed in this report for want of a better interpretation. It might be thought to represent a dropped or infolded outlier of the Tuscarora conglomerate, but there is even less agreement lithologically with the typical facies of this rock than with the finer conglomerates and the arkosic sandstones of the middle Martinsburg. Perhaps future detailed geologic mapping may demonstrate its age to be Triassic, and its origin to be like that of the Triassic conglomerates reported by Stose from areas that are similarly situated in point of structure and physiography farther southwest.² It should be mentioned, however, that similar limestone conglomerates are known to occur in rocks of approximately the same Ordovician age in Orange County, New York³ and in Rensselaer County in the same State.⁴

Upper Martinsburg member. As stated on a previous page the rocks here mapped as the uppermost member are regarded by Stose⁵ as the lowest member of the Martinsburg repeated by folding and differing from the latter because they have suffered less metamorphism. As Stose's interpretation is not established, and as the lithologic and

¹ Op. cit., pp. 650-651.

² Stose, G. W., Post-Cretaceous faulting in the Appalachians; Geol. Soc. Am. Bull. vol. 38, pp. 497-498, 1927.

³ Ries, Heinrich, Report on the geology of Orange County, New York; N. Y. State Mus., Rept., vol. 49, no. 2, 1895, p. 401.

⁴ Ruedemann, Rudolph, Trenton conglomerate of Rysedorph Hill and its fauna; N. Y. State Mus., Bull. 49, pp. 113-114, 1901.

⁵ Op. cit., p. 657.



A. Blocks of typical middle Martinsburg sandstone used as building stone.



B. Boulder of Spitzenberg limestone conglomerate.

PLATE 30.



A. Wrinkled lower surface of a sandy layer in a quarry in the upper Martinsburg; the beds are overturned, dipping steeply to the right; note wave-like surface along which next lower bed breaks free, to right of center of photograph.



B. Banding in soft slate, quarry near Slatedale; width shown, about 20 feet.

structural evidence seems to the writer to oppose it, they are treated here as a separate member.

This part of the Martinsburg formation, commonly called the "soft" slate, consists of three facies,—(1) beds of blue-gray, very sandy, almost quartzitic slate, in many places approximately a medium-coarse sandstone with calcareous cement, (2) blue-gray sericitic slate—the dominant rock type of this member—with occasional rare chloritic beds, and (3) dark gray or virtually black, highly carbonaceous beds, referred to popularly as "ribbons." These types of sediment generally alternate in a definite order,—a sandy bed below, followed in turn by a sericitic and then by a carbonaceous layer, though one of these may be omitted. Alternation of these facies gives a banded effect like that in the "hard" slate or lower member of the Martinsburg, except that individual layers are thicker. Thus, in the lower Martinsburg single beds seldom exceed six inches in thickness, whereas in the "soft" slate, or upper Martinsburg, beds up to five feet thick are very common, and thicknesses of as much as fifteen feet occur.

Relative thicknesses of a series of beds are sufficiently distinct to make an accurate correlation over appreciable distances possible. The sequence is described in detail under "Detailed Stratigraphy of the Soft Slate," page 184.

Two beds of greenish-gray chloritic slate are sufficiently continuous to serve as horizon markers. They evidently represent layers of impure, calcareous and probably also ferruginous mud deposited in the Martinsburg sea. The quarrymen call them "Gray" beds. They are further discussed in connection with correlation problems on page 192.

The sandy beds mentioned as one of the three prominent constituents of the "soft" slate rarely approach the heavier slate beds in thickness. They present the appearance in miniature of the basal sandstone that should be anticipated beneath a shale where the order of sedimentation is that consonant with the renewal of a sedimentary cycle. They are almost invariably followed in deposition by exceptionally thick beds of the lighter-colored phase of slate, as though there were indeed a genetic relation between the two. This relation is shown in the following examples:

Comparison of thickness of slate and sandstone layers

| Name of bed | Light gray slate, Inches | Basal sandy bed, Inches |
|--|--------------------------|-------------------------|
| Big bed, Albion-Bangor quarry | 60 | 4 |
| Big bed, Phoenix quarry | 58 | 7 |
| Big bed, Phoenix quarry | 50 | 3 |
| Red bed, New Diamond quarry | 98 | 9 |
| Big bed, Northampton quarry | 97 | 15 |
| Big bed, Northampton quarry | 82 | 31 |
| Middle big bed, Columbia Bangor quarry | 121 | 9 |
| North Bangor No. 3 big bed, Bangor Vein quarry | 153 | 35 |

Occasionally, as in the case of the Genuine big bed, Parsons quarry, an alternation of light and dark beds intervenes between the thick light gray and the sandy beds. Again occasionally a thicker "hard roll" will be followed by an unexpectedly thin bed of light-colored slate. These are, however, exceptions.

In some instances intraformational unconformities are seen beneath

such sandy layers, as shown in Figure 44. Frequently also the sandy beds show cross-bedding and ripple marks, the current generally coming from the east,—a fact which may obviously be used in determining whether beds are in the normal position or inverted (see Figure 45).

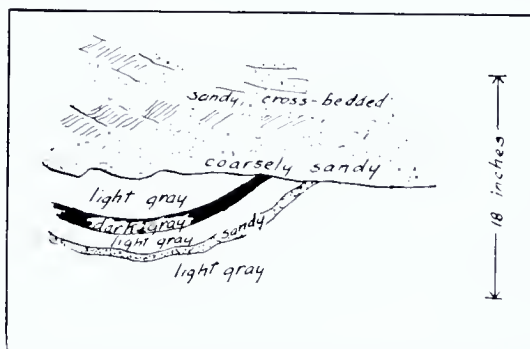


Fig. 44. Intraformational unconformity in block of slate from Kinnery quarry; the lower beds were eroded before deposition of the sandy stratum above.

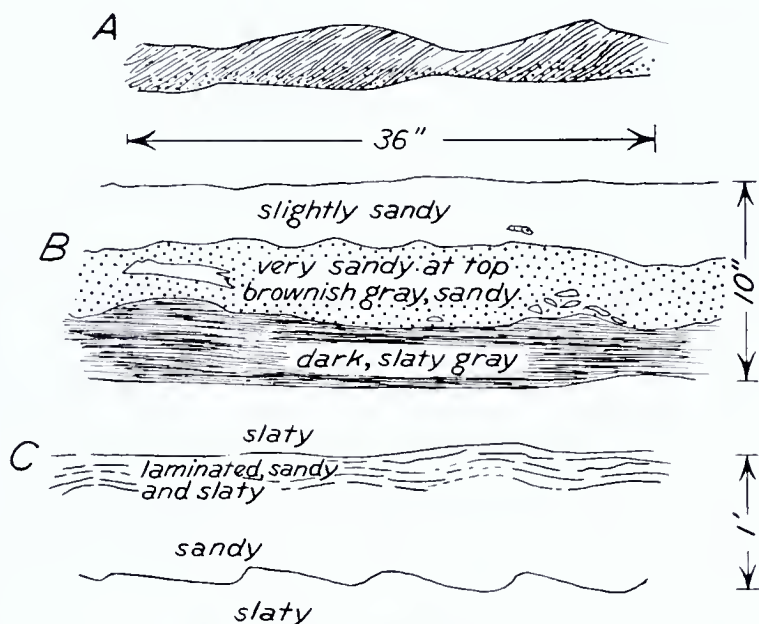


Fig. 45. A. Sketch showing cross-bedding in sandy layers in slate; the laminae dip west; Phoenix quarry. B. Sketch showing irregularities in bedding suggestive of shallow water deposition; slate from the Consolidated No. 1-Star quarry. C. Ripple marks in sandy layers; the beds are inverted; the current came from the left (east); Banger Vein quarry.

The rhythmic sequence of light and dark beds in the slate district has generally attracted the attention of geologists.¹ Careful measurements by the writer have shown that no rule governs the ratios between the thickness of dark beds and succeeding light ones. Barrell

¹ Cf., Barrell, Joseph, Rhythms and the measurements of geologic time; Geol. Soc. Am., Bull., vol. 28, pp. 803-804, Pl. 43, 1917.

thought the normal sequence consisted of very dark beds followed by sandy layers; this he attributed to settling in saline water after storms, the more muddy matter agglutinating before the sands came down. Very probably the cause—that is, differential settling after storms—is correctly divined, but clearly the sequence was purer mud followed by carbonaceous clays—the reverse of Barrell's idea. The most surprising feature is the sharpness of the line separating differing layers. This suggests marine sedimentation.¹

Other irregularities in sedimentation are shown in Figure 46. They represent irregularly-shaped fragments of beds in a matrix of another lithologic type. These cases are divisible into two groups,—one in

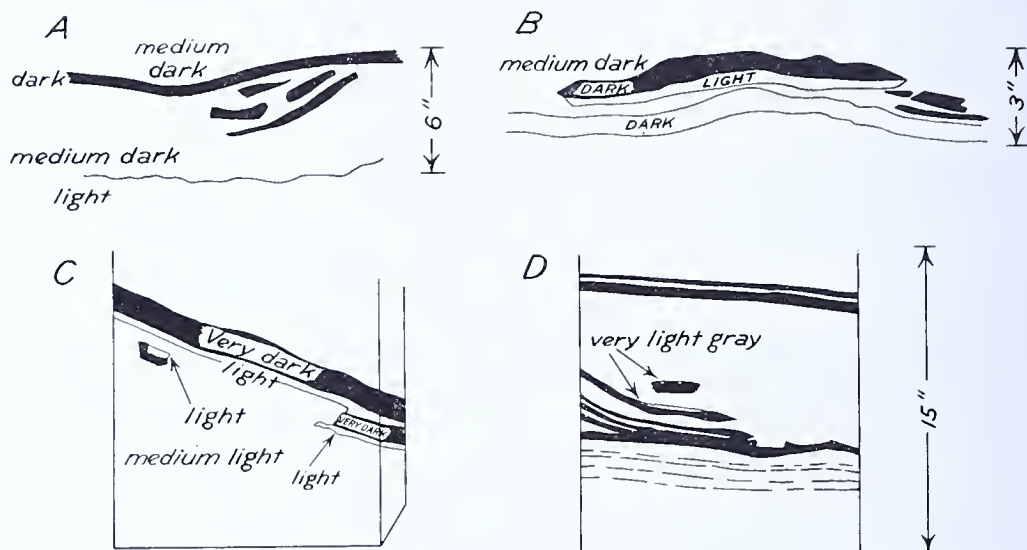


Fig. 46. A—C. Sketches showing irregularities in bedding in the carbonaceous layers of slate suggestive of intraformational conglomerates; B. is from the Bangor Central quarry, A. and C. from the North Bangor quarry. D. Irregularities in slate from Consolidated No.1-Star quarry. All unshaded parts are of normal light slate color, except as indicated.

which the isolated pieces are lenticular and the subjacent beds show no gaps into which they might fit; the other where the isolated pieces are sharply angular at their ends and appear torn from their original position by slight tectonic movements. Both of these types of fragments are illustrated in the drawings. They may be due to one of three processes: (1) small-scale faulting after all the beds were well consolidated and had long been laid down, (2) irregularities in primary deposition, or (3) slumping or other settling movements incidental to primary deposition but taking place after sufficient hardening of the deformed layers to permit them to act as competent beds. In most cases the latter seems to be the best explanation, but the occasional flakes of black, highly carbonaceous material which lie in places imbedded in slate of a totally different color and nature may represent mere irregularities in deposition.

Locally in this uppermost member of the Martinsburg formation there are beds of pure calcite, now coarsely crystalline. They are gen-

¹ Kindle, E. M., Diagnostic characteristics of marine clastics: Geol. Soc. Am. Bull., vol. 28, pp. 907-908, 1917.

erally very thin, seldom more than half an inch. The quarrymen speak of them as "silver ribbons" or, when the slate breaks parallel to them, as "loose ribbons." Rarely, as in the bottom of the Jackson-Bangor No. 6 quarry at Pen Argyl, have they been minutely fractured. These calcareous laminae are important from the structural viewpoint because movement between beds commonly took place along such "silver ribbons."

One of the interesting observations in the region is the disappearance of the upper member westward. Obviously its total thickness decreases toward the west, although there is no recognizable falling off in the thickness of individual beds in that direction. This fact is only explicable by assuming that an angular unconformity at the top of the Martinsburg truncates the beds, carrying the upper limit of the formation progressively lower and lower in the sequence. In other words, after the Martinsburg was laid down, it was uplifted and subjected to erosion, in such a way that in what is now the region of Schuylkill Gap the uplift and erosion were greater than at Lehigh and Delaware Gaps and more of the formation was worn away here than farther east. Indeed, the erosion immediately following the Martinsburg apparently went so far at Eckville, northeast of Hamburg, as to remove all traces of the upper Martinsburg in the neighborhood, though recognizable thicknesses of this member are present in the Lehigh River and Delaware River sections. In the Lehigh River section the total thickness as estimated by the writer is about 2355 feet, whereas Sanders, with less data available, made the thickness approximately 1529 feet.¹ In arriving at the latter figure Sanders recognized a fault² which the writer cannot accept. If this fault is not allowed for, Sanders' figure is materially increased.

Along the Little Bushkill, in Northampton County, where a poorly exposed section was measured by the writer, the thickness of this member appears to be 4415 feet,³ but the exposures here are discontinuous and the measurement may well be vitiated by repetition.

On the basis of these observations the thickness of the upper Martinsburg in eastern Lehigh and in Northampton counties may be about 2600 feet; reasons for believing in a westward reduction to 0 in central Berks County have already been given.

As to age, there is little definite evidence. If the sandy, middle Martinsburg represents the lower Maysville, then the "soft" slate is best regarded as of middle Maysville or later age,—that is, in the Cincinnati arch section it would be the time equivalent of Fairmount or McMillan or possibly even younger in part; no stratigraphic break is recognizable between it and the subjacent middle member.

TUSCARORA OR MEDINA FORMATION.

The formation immediately above the Martinsburg is a well-cemented, coarse quartzite with conglomerate layers and local thin interbeds of somewhat slaty shale. In the gaps on the Delaware and Lehigh rivers, this is the basal rock; it was spoken of as the Onondaga conglomerate by the Second Survey and said to be about 500 feet

¹ Sanders, R. H., *Geology of Lehigh and Northampton Counties: Pennsylvania*, Second Geol. Survey, Rept. D, vol. 1, pp. 135, 136, 1883.

² Sanders, R. H., *op. cit.*, p. 155 (figure).

³ Behre, C. H., Jr., *Slate in Northampton County, Pennsylvania; Pa. Top. and Geol. Survey*, Bull. M 9, p. 34, 1927.



A. Tuscarora-Martinsburg contact, east bank at Lehigh Gap; the talus slope covers the Martinsburg, except in the upper railroad cut.



B. Talus stream of blocks from Tuscarora cliffs, in valley three miles west of Pinnacle, Hamburg quadrangle.

thick.¹ Above this is a white, pure quartzite and quartz conglomerate, which weathers in white, light-gray or faintly pinkish colors. This massive rock generally forms the crest of Blue Mountain and, through its outcrops in an otherwise soil-covered country, as well as through the sharp relief that marks its presence, affords a much-desired clue to the structure of the mountain ridge.

At the Schuylkill gap a fault brings the upper, white quartzite member of the Tuscarora directly against the Martinsburg formation without the intervention of the lower conglomeratic quartzite.

Locally the purer quartzite beds in the upper part of this formation are quarried for sand, especially upon partial disintegration; a sand pit thus developed is half a mile due north of where the road leading westward from Eckville crosses Blue Mountain, in the Hamburg quadrangle. When fresh, the rock is sometimes used for building, for which purpose, though very hard and hence worked with great difficulty, it is well suited; talus blocks are then preferred, as their use obviates intensive quarrying. In parts of Pennsylvania some of the beds of the Tuscarora find favor as ganister,² but none is so utilized in the region here described.

The thickness of the formation was not measured, as the area mapped does not extend over the entire width of its outcrop. Nor was evidence obtained bearing on its age and correlation. There is fairly general agreement in referring the white quartzite and subjacent quartz conglomerate to the Silurian; Grabau³ so regarded it, as the result of his studies in central Pennsylvania, and Schuchert,⁴ in his summary of the sequence in the southeastern part of the state; Bassler⁵ in Maryland assigned the lithologically and stratigraphically similar Tuscarora quartzite to the Silurian and recently Ulrich has reaffirmed his acceptance of the Silurian age of the Tuscarora or white quartzite and quartz conglomerate at Delaware and Lehigh gaps.⁶ Thus the Tuscarora conglomerate and quartzite, taken together, may be definitely referred to the Silurian period.

Farther west, beyond Schuylkill River, other rocks, as to the correlation of which there has been much discussion, appear between typical Martinsburg and the Tuscarora; these, however, need not be considered here.

PLEISTOCENE DEPOSITS.

Over much of the area there are unconsolidated surface deposits, of a somewhat unusual nature. These are known to have been left by the great glaciers of the Pleistocene or "Great Ice Age." They are distinguished from river deposits, with which they are most subject to confusion, by the following features:

1. The generally subangular yet smooth shape of their boulders, in contrast with the rounded boulders characteristic of stream deposits.
2. The composition of the boulders: many of them are rock types

¹ Lesley, J. P., Summary description of the geology of Pennsylvania: Pennsylvania Second Geol. Survey, Final report, vol. I, pp. 639-643, 1892.

² Moore, E. S., and Taylor, T. G., Silica refractories of Pennsylvania: Pa. Top. and Geol. Survey, Bull. M 3, p. 18, 1924.

³ Grabau, A. W., The Medina and Shawangunk problems in Pennsylvania: Science, N. S., vol. XXX, p. 415, 1909.

⁴ Schuchert, Charles, Silurian formations of southeastern New York, New Jersey, and Pennsylvania: Geol. Soc. Am. Bull., vol. 27, pp. 545-548, 1916.

⁵ Bassler, R. S., Cambrian and Ordovician: Maryland Geological Survey, p. 173, 1919.

⁶ Ulrich, E. O., Written communication, 1927.



A. Gravel at pit near Martins Creek, typical of some of the overburden of the slate.



B. Glacial boulder from overburden near Berlinsville; note sub-angular shape.

foreign to the region, such as granite, schist, and the like, hence cannot have been derived by the wearing away of the local country rock by streams.

3. The arrangement of the material, in which boulders, sand, and clay are frequently mixed, with no definite assortment or deposition in beds, such as in stream materials.

4. The distribution of the deposits, which is patchy, not following definite channel outlines, as do gravel-bars or sand beds laid down by streams, but generally collected in discontinuous areas.

5. The topographic form assumed by the deposits: they are generally mounds, which may be either roughly equidimensional or definitely elongated in ground plan; between the mounds are commonly discontinuous, undrained depressions or "kettles."

Deposits of this type appear in various parts of the region. In many localities they grade more or less into stream deposits, because in such places the major contribution was made, not by the ice directly, but by the streams that flowed out from its front.

From Pen Argyl, in the central part of Northampton County, a recognizable terminal moraine—the material deposited at the immediate front of the ice—extends southeastward to near Belvidere, where it crosses the Delaware into New Jersey. Throughout this course it has a characteristic "hill and kettle" topography, and consists of mounds of gravel and boulder clay. On the Delaware Watergap sheet, it is clearly marked as a series of irregular hillocks averaging 30 feet in height, in the valley of Delaware River, one mile southwest of Belvidere. Westward from Pen Argyl this moraine was not traced in the course of the studies here reported, but as far west as New Tripoli in Lehigh County glacial deposits are fairly heavy, though not as thick as from Pen Argyl eastward. From New Tripoli westward all the way to Schuylkill River, and southward from Shochary Ridge the glacial deposits are scanty or are wholly lacking; if present at all they are so thin as to have little or no bearing on the possible quarrying of the slate.

TALUS MATERIAL.

Broken rock fragments from the cliffs of Tuscarora quartzite and sandstone on Blue Mountain have accumulated on the northern part of the area underlain by the Martinsburg formation. This material is known as talus. It attains a noteworthy thickness only close to Blue Mountain.

In the heads of some of the smaller valleys leading south from Blue Mountain such large talus blocks of Tuscarora quartzite are piled together in masses, locally forming rock streams half a mile wide and twice as long. These may represent glacial accumulations, but in view of the angular form of the blocks, they are more probably simply aggregates of talus pieces which have fallen into the valley from the semicircular wall of rock at the valley head. The best examples are to be seen in the upper valley of Pine Creek about two miles southwest of Eckville and in the heads of several of the smaller valleys that drain the south slope of Blue Mountain immediately north of Hamburg.

From the slate quarrymen's viewpoint these talus accumulations are of importance only where they form an appreciable cover above the slate.

STRUCTURE

GENERAL ASPECTS.

The region shows a monocline, striking about N.60°E. and dipping northwest at a low angle. Within this there are numerous folds,—some open, others closed, some with axial planes upright, others with axial planes slightly tilted, strongly tilted, or in some cases actually recumbent. In the quarrying these smaller folds are conspicuous and highly important in guiding operations.

Several thrust faults of larger dimensions, the strikes of which roughly parallel the trend-lines of the folds, are known, especially near Portland, at the eastern end of the district, and at Eckville near the western edge. Some small faults that have been studied in detail strike approximately at right angles to the thrusts and have steeply dipping planes and slight displacement, largely horizontal.

Detailed consideration of structures in any special region is given in the description of the corresponding quarries, the vertical sections, the geologic map, and the section on the effect of structural features (pages 194-195).

FOLDING.

Types. Close folding is the characteristic feature of the Martinsburg formation in the Lehigh-Northampton district. Indeed, the close folding, the scarcity of extensive outcrops, and the lack of good horizon markers make it probable that the detailed structure of appreciable parts of the district has yet to be worked out.

The simplest folding is that in which the axial planes are vertical or nearly so and in which the limbs are not greatly compressed, so that the opening angle of the fold is slight. There are no good illustrations of such simpler folding, but the Old Cambridge quarry, half a mile northwest of Slatington illustrates a fold dipping 65° to the horizontal and having an opening angle of about 80° between the limbs (see

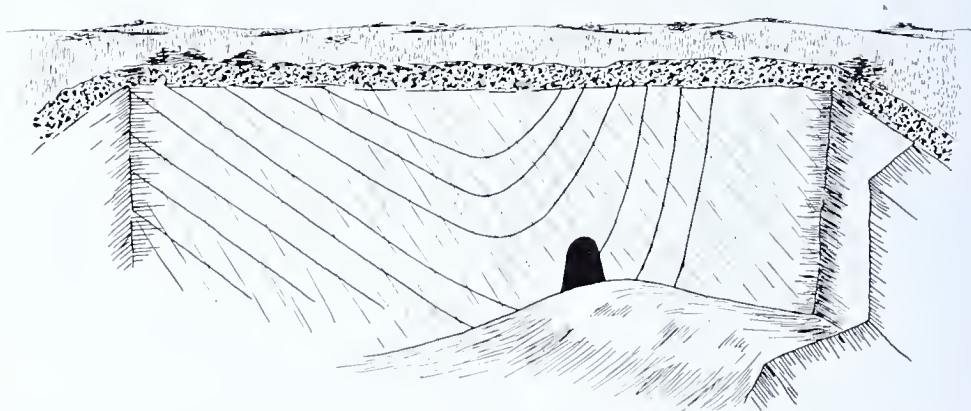


Fig. 47. View of fold in Cambridge quarry, Slatington, as seen from middle of southwest side; the fold is flattened slightly, because viewed from above.

Fig. 47). Similarly the Pittston, Blue Valley, and Eureka quarries, a mile northwest of Slatington show folds the axial planes of which dip southeast about 65°, but the fold limbs are nearly parallel and diverge by only 10°, if at all (see Fig. 48). The Manhattan quarry at Slatedale,

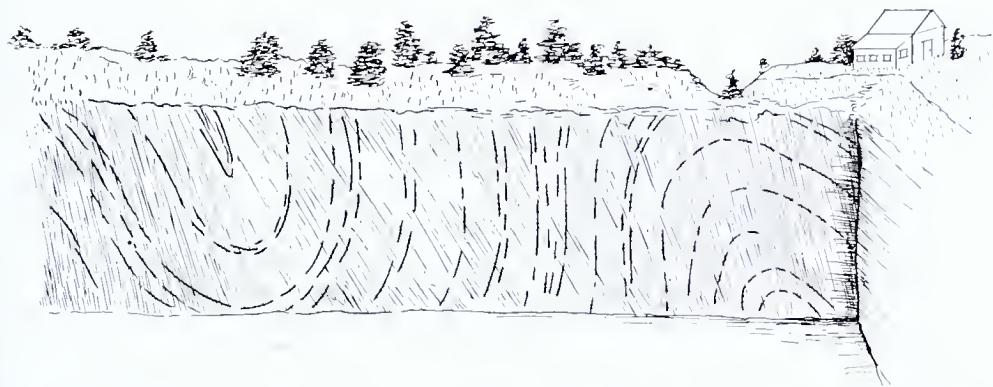


Fig. 48. Typical folding of the slate beds, as illustrated in the east wall of the Eureka quarry, near Slatington; cleavage shows as oblique lines from upper left to lower right; the beds are thrown into a southerly anticline and a northerly syncline with pitch of axial planes to the south.

2½ miles west of Slatington, shows an antieline, the axial plane dipping 45° S.E. and the limbs diverging about 65° (see Fig. 49).

Many of the folds are more highly tilted than those just mentioned, the axial planes virtually approaching the horizontal. Thus the Albion quarry at Pen Argyl shows a fold with horizontal axial plane, the limbs of which nevertheless diverge approximately 80° . The Old Bangor syncline at Bangor shows in several quarries. Its axial plane is horizontal or nearly so wherever observed, but the limbs diverge variously; northerly exposures show an opening angle of about 110° (North Bangor No. 3 quarry), whereas southerly ones open only about 50° (Old Bangor quarry).

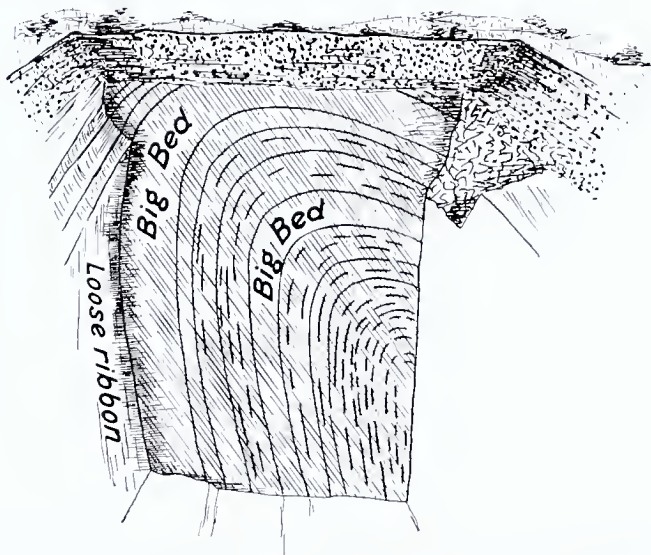
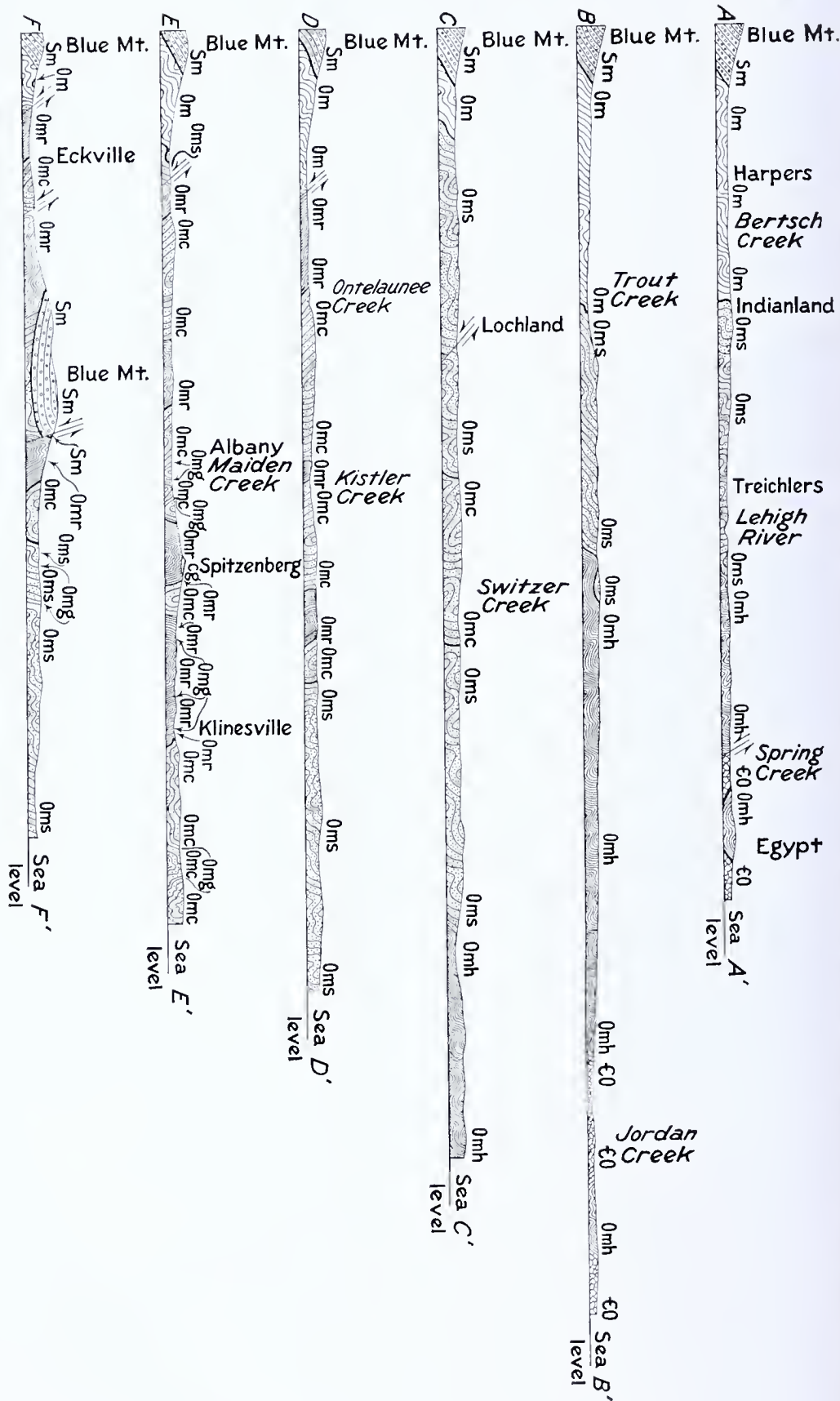
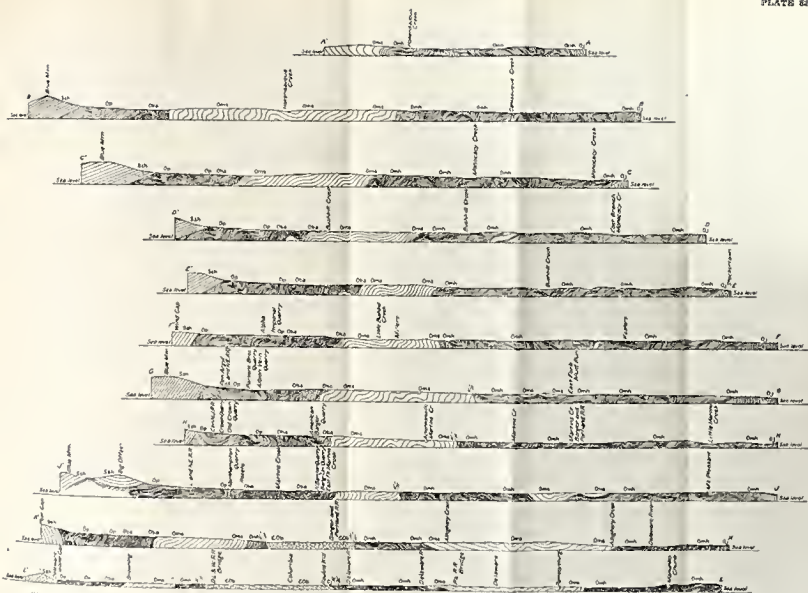


Fig. 49. Fold in northeast wall of Manhattan quarry near Slatedale.

It is a surprising fact that the limbs of folds, overturned even to the point where their axial planes are horizontal, show no tendency to approach each other more closely than where the axial planes are up-





Structure sections across state district of eastern Northampton County. Letters refer to corresponding letters on map, Plate 24. Scale as on Plate 24.

right. The beds accommodate themselves to this relation by very extensive thickening in crests and troughs. Because, to judge by the opening angle of the limbs, the thickening is the same whether the fold axis is horizontal or nearly vertical, there are strong reasons for believing that most of the folds, as first developed, had essentially vertical axial planes and that the tilting of the axes was a later episode in the diastrophic history of the Martinsburg formation.

Pitch in folds. All of the folds in the Lehigh-Northampton district have pitch. In cases where the folds have axial planes that are nearly vertical, the effect of the pitch is to impart to the trace of the fold, when plotted on the horizontal plane, a "canoe-shaped" outcrop. In such a structure the beds will nowhere attain actual horizontality, for even on the crest of the fold there is a dip in the direction of the pitch.

A far more complicated situation, however, is presented where the axial plane is horizontal or nearly so. If the plane of the surface and axial plane are parallel the outcrop line is simple, but if the two planes intersect, the outcrop lines are curved and a reversal of dip along the strike may result. An illustration is furnished by the American Bangor and Bangor Southern quarries $1\frac{1}{2}$ miles southeast of Bangor. At the Bangor Southern the strata strike $N.57^{\circ}E.$, and dip approximately 25° N.W.; at the American Bangor, about 900 feet east, the strike averages $N.65^{\circ}E.$ and the dip about 20° - 25° S.E. This relationship is explained by Figure 50.

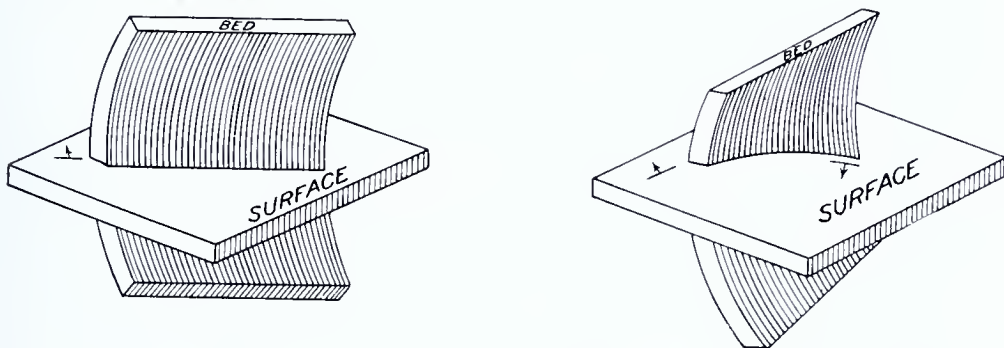


Fig. 50. Fold with horizontal or gently dipping axial plane; to illustrate effect of pitch on line of outcrop and direction of dip. Left figure shows fold with horizontal axial plane but without pitch, right figure shows recumbent fold pitching, with a reversal of dip along the strike.

Details of folding, eastern part of district. For convenience, observations on the folding from Delaware River to the meridian of Slatefield are treated separately from those made west of Slatefield.

On Delaware River at Portland a prominent anticline extending southwestward brings pre-Martinsburg limestone to the surface; it is bounded by faults described below.

On Delaware River at the town of Delaware the coarse, sandy layers of the middle Martinsburg appear in a syncline, bordered by the lower Martinsburg, both north and south. This syncline is followed westward with difficulty, but the sandy beds of the middle Martinsburg still cap the hills south of Factoryville on the Delaware Watergap quadrangle. An easterly pitch probably accounts for the dying out of the syncline westward.



A. Small syncline (on right edge of picture) and larger anticline in slate near Albany Station, Berks County.



B. Fault between Martinsburg (right) and Tuscarora (left) formations at P. & R. R. cut, Schuylkill Gap.

All other folds are lesser structural features, and are detected only in connection with quarry operations. Thus in the "hard" slate several minor synclines and anticlines have been studied in the quarries at Belfast and the Chapman quarries two miles north of Bath.

The Big Offset and the Little Offset, which show topographically as sigmoid flexures of the crest of Blue Mountain, are both synclinal folds pitching westward and separated by a similarly pitching anticline of the Tuscarora formation at the head of the West Fork of Martins Creek. This structure is reflected by the slate itself. Thus, at Bangor the Old Bangor syncline, with an axial plane dipping about 4° S., is one of the conspicuous folds of the slate belt. At the New Peerless (Bangor Vein) quarry, $2\frac{1}{2}$ miles northeast of Bangor, a similar syncline with flat axial plane is exposed. These folds appear to be parts of a larger structure,—a syncline whose axis lies well north of the town of Bangor. This fold has a westward pitch, the axis emerging at the Shimer, Consolidated No. 3, and Mountain View quarries $1\frac{1}{4}$ miles north of East Bangor. It may, in turn, be only a major drag fold on a still larger synclinal unit, but evidence for such an interpretation is still lacking, as the beds are covered northward by younger formations.

West of Bangor the structures are a series of parallel folds, generally with axial planes that vary from nearly horizontal to dips of 25° S. In some quarries, such as the Albion Vein, several folds are encountered as depth is attained. In the Jackson Bangor Nos. 7, 6, and 5 quarries the strata at the surface dip south; from the Acme and Alpha to the Phoenix quarries they dip north on the south limb of a syncline. From the Tinsman quarry west it is apparent that the surface structure on which the greater part of the openings are located is the north limb of an overturned anticline, the axial plane of which dips south. Thence westward to Slatefield there is no clear evidence as to the dominating structure.

Details of folding, western part of district. West from the region of Slatefield the axial planes of folds more nearly approach the vertical. This is the outstanding structural difference between the regions east and west of Slatefield.

There are several jogs in the otherwise uniform monoclinical structure from Slatefield west. In the neighborhood of Newside on the Slatington quadrangle a broad tongue of "hard" slate of the lower Martinsburg projects northwesterly into the main area of the middle, sandy member, suggesting a southwestward pitching anticline. Similarly, at Snydersville, Guthsville, and Stetlersville (Slatington quadrangle), a long, slender strip of the lower Martinsburg member extends easterly into territory underlain by limestone; this in turn suggests a westward pitching syncline in the Martinsburg. The structure is referred to as the Snydersville syncline. Half a mile south of Laros on the same quadrangle Dale has mapped another such prong projecting into the belt of limestones, probably for the same reason. Haas Hill, one mile south of the last locality, is a synclinal remnant.

The region of Mosserville shows a westward pitching anticline of middle Martinsburg which splits the strip of uppermost Martinsburg between Shochary Ridge and Blue Mountain.

The several sigmoid flexures of Blue Mountain between Eckville and the Schuylkill River indicate a series of pitching anticlines and syn-

clines locally broken by faults. The details of these structures can best be seen in the corresponding vertical sections.

The most pronounced folds affecting the Martinsburg in this region are two great synclines of the sandy beds of Pulaski age which form respectively Shochary Ridge and the next prominent sub-parallel ridge of sandstone to the south, which extends eastward from the Pinnacle on Blue Mountain toward Wessnersville. Between these two ridges lies a depressed area, its length extending eastward and its width reaching from Kempton to Trexler. This represents an anticline between the sandstone of the two synclinal ridges mentioned and exposing shaly beds probably corresponding to those immediately north of Shochary Ridge in which, west of Eckville, an Eden fauna was found (as mentioned in the description of the middle member of the Martinsburg).

Several minor folds are shown in the outcrop-pattern of the red, green, and yellow clay slates quarried for crushed stone near Albany, Greenawald, and Lenhartsville.

Detailed structure of the "soft" slate belt consists of a series of folds illustrated in the large-scale cross sections (see Plates 55 and 56).

FAULTING.

Types of faulting. If faulting be regarded as movement of one solid rock mass past another along a definitive plane or planes, six types of such movements may be recognized, which, although not all faulting in the strictest sense, can yet best be treated under this head. These six types are:

1. Faults of large displacement and great horizontal extent, approximately parallel to fold axes,—chiefly thrust faults.
2. Smaller faults of moderate displacement, inclined to the fold axes.¹
3. Bedding-slip faults.
4. Small-scale faulting in calcareous beds.
5. Movement along bedding planes,—not true faulting.
6. Movement along cleavage planes,—not true faulting.

All of these except Types 1 and 2 are of common occurrence in the district, and hence no attempt will be made to describe all occurrences of the latter four kinds of movement. A short description of each of the occurrences of Types 1 and 2 will be given, however.

The simplest fault nomenclature is preferred. Fault plane, strike and dip of fault plane, hanging wall and foot wall are self-explanatory; normal and reverse faults are terms well understood.

Throw is the vertical component of the displacement along the fault plane; heave is the corresponding horizontal component.

Faults of large displacement and great horizontal extent. Of these there are only seven in the district.

One fault enters this region at Delaware River about 0.9 mile south of Slateford, and extends southwestward, so as to have a surface trace trending N.45°E. West of Delaware River the evidence for this fault is almost wholly lacking, although an abrupt escarpment of 20-40 feet, about 0.8 mile north of Portland, where limestone on the south probably comes against hard slate on the north, suggests its presence. In drilling for the piers of the Delaware, Lackawanna & Western Railroad bridge

¹ Since this was written detailed work by Prof. Freeman Ward has indicated the occurrence of several smaller thrust faults in the exposures along Delaware River.

about a mile above Portland, slate alone was encountered. The trace of this fault therefore passes south of the bridge.

In the valley of Jacoby Creek west of Portland and in a large pit about 700 feet south of the post-office of that town, the upper part of the Cambrian limestone, dipping gently southward, is exposed. Just across the river, in the railway cut east of Columbia more of the same limestone is seen. Three-quarters of a mile north of Columbia and about half a mile east of the river Cambrian limestone is again seen in the railroad cut of the Delaware, Lackawanna & Western Railroad. About $1\frac{1}{4}$ mile due west of Hainesburg, N. J., a northward trending road zig-zags upward to an altitude of 450 feet. Here the hill on the east side of the road is covered by Cambrian (probably Allentown) or early Ordovician limestone, while on the western side a small quarry exposes typical closely banded hard slate, striking $N.55^{\circ}E.$, and dipping $28^{\circ}N.$ The fault plane is thus clearly limited on the surface to a strip not over 50 feet wide. It is most probable that the limestone here exposed is near the top of the Allentown formation. The maximum thickness of beds lacking between the Allentown and Martinsburg is:

| | |
|-----------------------------|------------------|
| Jacksonburg limestone | 550 feet |
| Beekmantown limestone | 1250 feet |
| Total | <u>1800 feet</u> |

Assuming a dip of 10° , the vertical throw of this fault is at least 1850 feet.

The dip and strike could nowhere be determined with accuracy. As the fault is associated with very steep dips and parallels in a general way the strike of the beds, and as the strata appear to have an increasingly steep northerly dip as they approach the plane of movement, the assumption seems justified that this is a reverse or thrust fault. Reasoning by analogy with other Appalachian faults of this general character, the dip southward is probably gentle; as the fault trace on a fairly level surface trends $N.45^{\circ}E.$, this may be assumed as the approximate strike. The eastward continuation of this fault has been mapped by the geologists of the New Jersey Survey¹, who regard it as a "thrust fault along which the slate has been pushed over upon the Kittatinny limestone for a short distance."

About half a mile south of Portland, on the west side of Delaware River and west of the Delaware Water Gap highway there is evidence of another fault. The eastern continuation of this, too, has been mapped by the New Jersey Geological Survey. The western extension trends about $S.50^{\circ}W.$, between a quarry opened in the lower, bryozoan-rich part of the Jacksonburg and the lower beds of the Martinsburg, chips of which are exposed at 400 feet on the hill to the south. The fault trace can be followed on the east side of Delaware River by similar evidence, but on the west bank the glacial cover is too heavy and the only positive evidence is the line of springs appearing at the foot of the slate escarpment between Mount Bethel and the river. Westward this fault probably merges with the thrust fault first described, which, judging by the apparent thickening of the middle member of the Martinsburg north of the fault plane as the latter is followed westward, dies out somewhere in the neighborhood of Ackermanville.

¹ Kummel, H. B., Report on Portland cement industry; N. J. Geol. Survey, Ann. Rept. for 1900, pp. 63-65, 1901.

The plane of the fault last described is not exposed anywhere; the most southwesterly of the limestone quarries in the field half a mile south of Portland, however, shows lower Jacksonburg limestone dipping steeply southward, heavily slickensided in places, and thus showing every indication of having been dragged downward by having the slate move down against the Jacksonburg limestone on the fault plane. The stratigraphic throw of the fault is certainly less than 500 feet. The strike is thought to be about N.50°E., parallel to the trace.

Half a mile south of Slateford a thrust which is not exposed is inferred to narrow the width of outcrop of the lower Martinsburg.

No faults of large displacement are recognized west of those described until the west edge of the Slatington quadrangle is reached. It is nevertheless altogether likely that there are faults, and even some of major importance, in this region; the lack of good exposures, but more especially the absence of continuous key horizons that might serve in interpreting structure, may preclude their recognition.

The rugged ridge, known as Shochary Ridge, which appears south of Ontelaunee Creek on the Hamburg quadrangle, is as stated, a synclinal ridge of middle Martinsburg rocks, consisting chiefly of coarse sandy clay slate, sandstone, and even some fine conglomerate. North of it is a valley followed by two of the heads of Ontelaunee Creek and underlain by a slate which shows "ribboning" not unlike that of the "soft" slate but generally in thinner beds. Northward beyond this, in turn, is a low ridge or "hogback" roughly a mile south of the crest of Blue Mountain and parallel to the latter. This is underlain by a belt of coarse sandstone suggestive of the middle member of the Martinsburg. The "hogbacks" and sandstone die out eastward, being unrecognizable approximately half a mile west of Jacksonville. North of this belt is typical "soft" slate, with characteristic carbonaceous "ribbons;" it is opened in the quarries north of Quaker City, north and west of Slateville, and half a mile north and northeast of Wanamaker.

These areal relations are subject to several interpretations. Relative attitudes of bedding and cleavage are of no aid because too variable. The interpretation accepted therefore depends largely upon the stratigraphic positions assigned to the sandstone forming the "hogbacks" and to the belt of slate lying between these and Shochary Ridge. A very poor collection of fossils from the sandstone of the "hogbacks" was submitted to Ulrich, who recognized the following forms:

Dalmanella sp., *Plectorthis* () sp., *Sowerbyella* sp., *Aparehites* (?) sp.

Ulrich regards this fauna as probably indicating Pulaski age, and hence referred to a horizon in the middle Martinsburg. On this basis a simple and consistent interpretation is that the sandstone in the "hogback" represents the highest sandy beds in the sandstones of the Shochary syncline, here dipping northward again, while the slaty shales between the "hogback" and Shochary Ridge are strata (similar to those between Kempton and Trexler) lower than the "hogback" sandstone and than the other sandy beds of the Shochary Ridge syncline and reappearing from under the sandstones in an anticlinal crest. If the apparent "soft" slates exposed in quarries north of the "hogback" are really uppermost Martinsburg, therefore, there must be a fault between them and the sandy beds of the "hogback," the "soft" slate

and a small thickness of underlying sandstone having been dropped down until they abut against the slaty beds of the middle member between the "hogback" and Shoehary Ridge.

This interpretation is favored not only by the close crumpling on both sides of the presumptive fault zone but also by vertical dips south of the fault and by the strikingly linear arrangement of some prominent springs, such as half a mile east of Slateville and again half a mile west of Jacksonville. It is very greatly strengthened, further, by the finding of a major fault, described below, at the conspicuous elbow in Blue Mountain west of Eekville, where there is a marked areal offset in a cliff-forming series of beds in the Tuscarora formation, which is clearly recognizable on the topographic map. The offset consists of a westward jog south of a line which is continuous with the horizontal strike projection of the fault hypothesized in the Martinsburg. The fault trace on Blue Mountain would seem to trend $N.75^{\circ}E.$ Its stratigraphic displacement in the vertical direction may be computed by setting up a geometrical problem, given horizontal displacement of the Tuscarora ledge-forming bed, the measured dip of the Tuscarora beds, and the bearing of the fault trace mentioned above. Minimum and maximum possible displacements amount to 775 and 825 feet respectively,—ample to cut out by faulting virtually the entire thickness of sandy beds exposed in the Shoehary Ridge syncline. This fault, from the crest of Blue Mountain west of Eekville to where it dies out east of Lynuport, will henceforth be referred to as the Eekville fault.

A fault approximately parallel to that just described is inferred from the offset of the Tuscarora quartzite about one mile due southwest of Eekville. Dip and trend are based on presumptive evidence only, and hence the fault is indicated on the map with a broken line.

At the Pinnacle, $2\frac{1}{2}$ miles west of Albany, the beds are flat. On the 1460-foot hill one mile south of the Pinnacle the strata dip gently northwest. Between these two prominences there is a topographic gap, inferred to represent the effect of differential erosion on a shattered zone. The topography and the abrupt change in dip suggest, but by no means prove, the presence of another, probably small fault here. This displacement is believed to continue westward but cannot be traced clearly in the field. However, on the road that leads northwest from Lenhartsville up the slope of Blue Mountain, between the altitudes of 900 and 1200 feet there is a sharp reversal of dip strongly suggesting a fault; at 940 feet the Tuscarora strikes $N.75^{\circ}E.$, and dips $70^{\circ}N.$, whereas at 1200 feet it strikes $N.60^{\circ}E.$ and dips $15^{\circ}S.$ A fault is inferred between these two points.

It is very likely that this fault is continuous with that at Schuylkill River. The latter does not actually show on the east bank of Schuylkill River, but on the west shore it is clearly seen in several places. It is well exposed in the cut of the Pennsylvania Railroad, 1800 feet south of the Port Clinton station, again on the Reading Railroad at the west side of the curve 1000 yards south of the Port Clinton station, and on both sides of the same tracks about half a mile farther southeast. At the first of these localities the slate south of the fault dips gently south, whereas north of the fault is dense, gray, thick bedded Tuscarora sandstone, striking $N.55^{\circ}E.$ and dipping $70^{\circ}N.$ At the second locality the Tuscarora is a heavy white quartzite like that forming the crest of Blue Mountain; it strikes $N.60^{\circ}E.$ and dips $70^{\circ}N.$ At the third locality,

the Tuscarora is conglomeratic, strikes N.75°E., and dips vertically, whereas the slate, represented by alternately slaty and sandy beds, strikes N.20°E. and dips 20°S. The strike of the fault at these points is, respectively N.68°E., N.65°E., and N.78°E., and the dip is steeply south,—roughly 80°. The fault is thus an exceptionally steeply dipping thrust.

This fault, with its probable eastward extension beyond the Pinnaele, will hereafter be referred to as the Schuylkill Gap fault. There are grounds for suspecting that it continues east of the Pinnaele, up the valley of Kistler Creek, but for this the evidence is too poor to permit mapping.

Two miles south of Laurys a fault brings limestone against slate (see Plate 25). This fault is seen on the road at the east end of the reservoir (not shown on the map) half a mile west of Lehigh River. There are also several abnormal outcrops of limestone possibly due to faulting, in areas surrounded by slate, especially along Maiden Creek in the vicinity of Virginville. These have not been studied in detail, however.

Attention should again be directed to the reconnaissance nature of the field work in eastern Berks County, especially along the southern edge of the Martinsburg formation. Naturally such a generalized study precludes the detailed mapping of many faults.

Smaller faults of moderate displacement, inclined to fold axes. So far as known these are only illustrated in the quarries of the Pen Argyl group, where at least six are definitely recognizable¹. Faults of this type strike at large angles to the general strike of the beds and have small displacements,—in the observed cases none exceeding 70 feet. Two examples may be cited.

In the Jackson Bangor No. 6 quarry on the lowest level (depth about 345 feet) a fault of this type, with small displacement, is seen on the quarry floor and on the northwest wall. Its strike is generally N.10°-27°W., and the dip is 25°NE. The beds on the under side of the fault have moved northward about 9 feet along a line normal to their strike. As there seems to have been a horizontal component to this motion, the actual displacement in the fault plane was probably greater, 38 feet along the striae of the plane, which trend 60°W. The fault plane is tightly closed, and in many places scarcely recognizable or seen only as a very faint crack.

In the bottom level, in the extreme southwestern corner of the same quarry, a small part of a new fault surface was exposed by channel cutting in December, 1923. This strikes N.35°W., and dips 15°NE. It is approximately the proper level to represent an eastward continuation of a fault said to have been found in quarrying at a depth of 160 feet in the Jackson Bangor No. 7 quarry. The striae observed trended N.25°W., approximately parallel to the strike of the fault plane. As the beds below were not yet exposed, the offset could not be measured.

In view of the approximate similarity of these two faults in other respects, the difference between the direction of their striae may be explained by assuming for the hanging wall of both a horizontal southward movement and for the upper fault a downward movement as well (see Fig. 51). The true movement along the two faults, as far as can

¹ Behre, C. H., Jr., Slate in Northampton County, Pennsylvania: Pa. Top. and Geol. Survey, Bull. M-9, pp. 63-65, 1927.

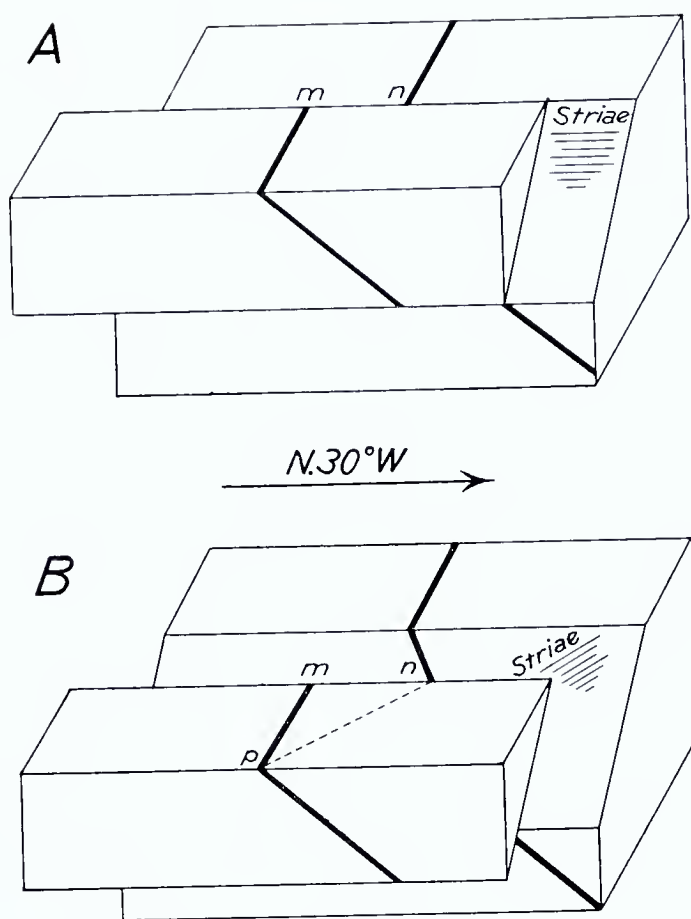


Fig. 51. Diagrams to show relation of striae to direction and amount of displacement of faulted blocks in Jackson Bangor No. 6 quarry, Pen Argyl. A. Lowest fault, with striae trending about N.30°W.; B. Upper fault, with striae trending N.60°W.

be ascertained, is qualitatively represented in Figure 51, in which Diagram A represents the lower fault and Diagram B, the upper. The front face of both diagrams has a strike of N.30°W. and the direction of the striae is indicated on both. In addition Diagram B shows why the displacement measured along the striae (pn) is greater than where measured along the strike of the fault (mn).

Other similar faults, all at Pen Argyl, are known in the Albion quarry at a depth of 490 feet, in the Jackson Bangor No. 7 quarry at a depth of 160 feet, in the Jackson Bangor No. 6 quarry high up in the southeastern wall (—this is continuous with a fault near the bottom of the Jackson Bangor No. 5 quarry), and near the surface in the northeast corner of the Jackson Bangor No. 5 quarry.

It thus appears that there is a system of faults trending northwest or north and with largely horizontal displacement. These may be as late as Triassic in age, or they may represent post-Martinsburg or post-Carboniferous relaxation after a period of thrusting. Or finally, they may actually be high-angle thrust faults that relieved a horizontal compression by permitting the forward movement of individual segments,—a feature often observed on a grander scale at the borders of

thrust blocks. The last explanation is, in the light of facts so far obtained, the most acceptable.

Bedding slip faults. These are faults which are associated with close folds, and in which most of the movement takes place at such a low angle to the bedding that an actual plane of faulting distinct from the bedding planes can only be recognized with difficulty. For such faults the term bedding slip is here proposed. Some of the features referred to as "loose ribbons" by the quarrymen are bedding slip faults. The attention of the observer is first directed to the fault when he finds that the attitude of the upper (inner) beds in a close syncline is not like that of the lower beds. Closer inspection then reveals the fact that near the axis of the fold these upper beds describe a larger arc than do the lower ones, hence that the lower strata are truncated by the upper ones. In short, there is a fault surface parallel with the upper beds, hence the term bedding-slip fault. Associated with this feature is generally a severe mashing of the beds, with irregular cleavage, closely spaced jointing, and much deposition of quartz and calcite in open cavities.

Examples of this feature are numerous. The north wall of the Albion pit is perhaps the most striking case in the region, rivaled only by the north wall of the Bangor Vein (New Peerless) quarry. There is a suggestion of the same feature in the north wall of the Jackson Bangor No. 6 quarry near the surface. The Albion Vein quarry shows a similar feature on the north wall. The Bangor Fidelity and West Bangor quarries show a slip fault along the bedding about the middles of their side walls, and traces of its continuation are preserved in the Crown quarry to the west (See Plate 51). Finally, a trace of a similar feature is to be seen midway between the "back" and "front" ends of the opening in the northeast wall of the Northampton quarry. In the Slatington district the feature is rare. Two outstanding examples may here be described,—both from the Bangor-Pen Argyl region.

In the New Peerless (Bangor Vein) quarry, two miles northeast of Bangor, the beds curve sharply into a syncline having an axis that dips southward only about 8° ; the general bedding strike is $N.40^{\circ}E.$ Immediately south of the north wall of the opening, the beds curve gently in the trough of the syncline and the cleavage surfaces are horizontal and plane, but 10 feet farther south the dips of the synclinal limbs flatten and the cleavage becomes crenulated, as though greatly compressed after its formation. A sketch of this part of the fold is shown in Figure 52, A. The fault plane itself approximately parallels the northern, less compressed beds and is open in places, with a filling of quartz and calcite, much of the latter having been dissolved away subsequently.

In the Albion quarry the northwestern wall is cut into a series of reentrants. At about the middle of this side of the opening there is a remarkably smooth bedding face. The bedding north of this face curves gently to form a rather open syncline, but southward the fold is more tightly compressed, with a noticeable bulge at the axis. Heavy and closely spaced jointing is conspicuous at the bedding surface marking the contact between the more tightly and the less severely compressed parts of the fold. The plane of contact strikes $N.57^{\circ}E.$, and varies its dip with the bedding. It is heavily slickensided and coated with quartz and calcite. Vertical joint planes are well developed under the

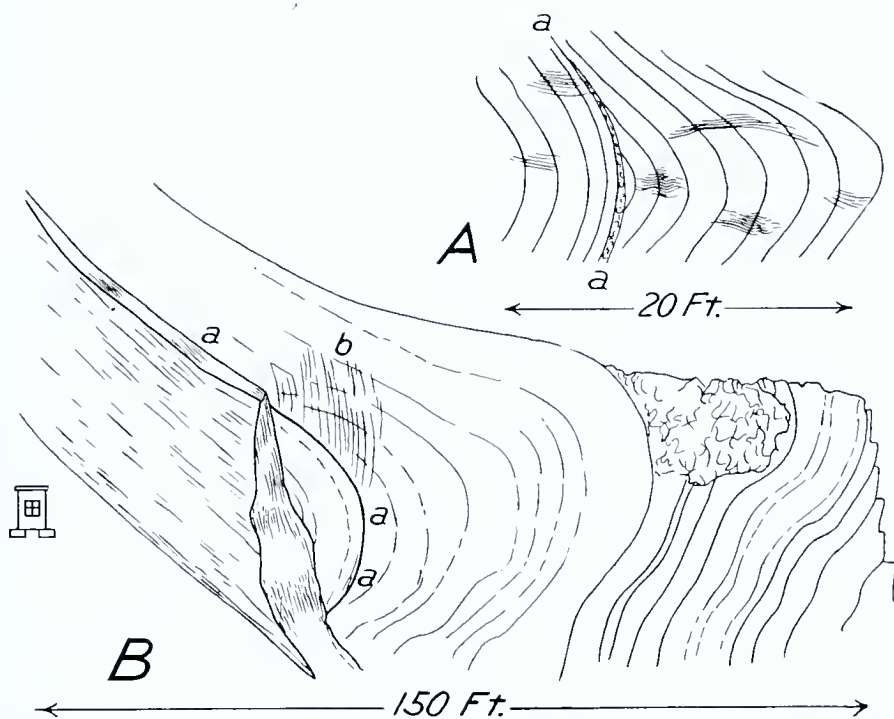


Fig. 52. Bedding slip faults: A. in Peerless quarry, northeast wall; shows bedding slip plane (a—a), the lower part of which is a quartz filled crevice; B. in Albion quarry, viewed from southwest wall; shows fault plane (a—a) and vertical joints (b).

axis of the fold; above it they are similar, dipping 80° S. For a diagram of these relationships, see Figure 52, B.

Such faulting is subject to two interpretations. It may be due to horizontal movement along curved fault planes almost but not exactly tangential to the curvature of the beds at fold troughs or crests. The effect would be to carry the fault plane across the bedding. The objections to this explanation are twofold. First, in the case of all such faults where slickensides were observed the movement indicated was vertical, or nearly so; this fact suggests that the chief movement was vertical, though it by no means proves as much, since slickensides are frequently developed by later insignificant movements which may differ in direction from the main displacement. Second, and of far greater weight, is the difficulty of picturing the mechanics of horizontal movement along planes which strike northeast when the thrust is otherwise known to be directed northwestward.

An alternative explanation is to look upon faults of this type as furnishing a way for relieving excessive pressure in fold axes. The attitudes of the beds and joint planes suggest that bedding-slip faults are a means for permitting the close compression of the lower beds in troughs while the upper beds retained their form in folds that were relatively open. The movement along the fault planes would thus be chiefly in the vertical direction and in accord with the fault striations mentioned above. An idealized diagram, assuming this explanation, is given in Figure 53. Though better than the first, this theory is yet not wholly acceptable.

In any case, the disturbed cleavage proves that the movement took

place after sericitization; if the period of cleavage development of the slate be regarded as post-Martinsburg, pre-Tuscarora, these faults must clearly represent an adjustment to thrust of a period somewhat later than the Martinsburg.

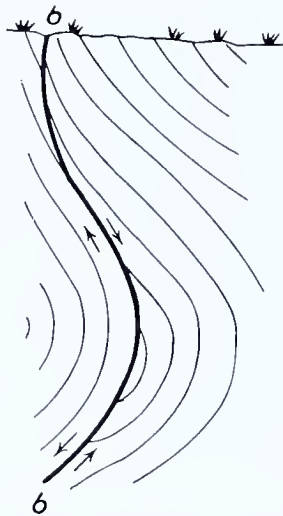


Fig. 53. Diagram of ideal bedding slip fault; b-b, fault plane; arrows show apparent direction of movement.

A matter of interest is the rarity of such faults at Slatington, at least, in so far as observed. The suggestion may be ventured that adjustment of this type becomes necessary only when the fold axes are horizontal or nearly so; for this, however, there is no obvious reason.

Small-scale faulting in calcareous beds. In many places the occasional calcareous beds are broken by numerous faults, which have approximately horizontal planes. In such instances each little segment of the limy bed has glided over that beneath it, so as to yield many small faults, which, as they parallel the axes of tiny drag folds, may be spoken of as “drag faults.” It is significant that the faults never pass into the slaty beds on either side, but die out at the edges of the calcareous beds, although a parallel suite of drag folds is sometimes visible in the slate adjoining the limy bed. The fault planes in the calcareous beds are generally coextensive with the cleavage.

An illustration of this type of minute faulting is given in Plate 4 and Figure 54.

Movement along bedding planes. In a series of beds as severely folded as those of the Martinsburg, movements along bedding planes are to be expected and are, indeed, of common occurrence. They are particularly noticeable in the middle, sandy member, where they are commonly associated with false cleavage and with “wrinkling” of the bedding surfaces. They are also commonly seen in association with the more calcareous beds in the soft slate. These calcareous beds are called by the quarrymen “silver ribbons.” As they are subject to solution by percolating waters, they commonly become separated from the slate beds on either side, leaving a discontinuous crevice, along which the slate parts; in such cases, the quarrymen refer to the

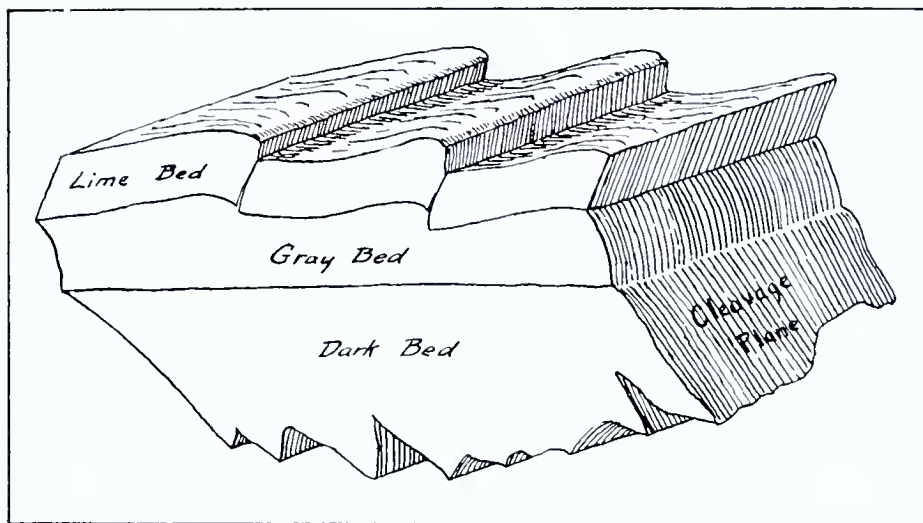


Fig. 54. Mullioned calcareous bed, closely faulted, and undistorted slate beds below it; the upper surface of the specimen is heavily striated. Length of specimen, 10 inches.

calcite beds as "loose ribbons." A surface of a "loose ribbon" commonly bears slickensides or striae, showing that movement has taken place along it (see Figure 54).

Movement along cleavage planes. The movement along cleavage planes is considerably evidenced in the slate. It is most noticeable in the hard slate. Here it is not uncommon to find quartz or calcite lying in the cleavage, and occasionally striae are still preserved on the cleavage filling. In places, joints suggestive of tensional cracks and also filled with calcite, quartz, or a mixture of both, cut the cleavage vertically in such a way as to suggest tensional joints; as they die out both above and below, the suggestion is that either their upper or lower ends mark the intersection with the cleavage plane along which slippage took place.

An illustration of such movement is seen in the east wall of the Belfast quarry. Here a zone about ten inches wide has undergone shear along cleavage, with the development of openings and the deposition of quartz in the openings so formed (see Plate 11, A). This is probably comparable to Dale's cleavage banding¹.

CLEAVAGE.

Degree of development. Cleavage is not uniformly developed throughout the Martinsburg formation. In general, those beds of which the composition before metamorphism most closely approximated a shale are those in which the cleavage is best developed. Sandy layers especially militate against good cleavage in the slate.

In the "hard" slate the thin beds are crossed by cleavage that is very faintly wavy, but not enough so to interfere in the least with use in roofing. In the "soft" slate cleavage is especially well developed and wholly without deflection (even where it intersects the carbon-rich "ribbons"), except in crossing the sandy "hard rolls" that gen-

¹ Dale, T. N., *Slate in the United States*; U. S. Geol. Survey, Bull. 586, pp. 45-48, 1914.

erally underlie exceptionally thick beds. In the middle member of the Martinsburg the cleavage is poor, and some of the blocky, sandy layers have a parting which, in spacing and direction, corresponds more nearly to jointing than to cleavage; these strata are obviously not usable for slate making.

Dip and strike. Throughout the district, the dominant strike of the cleavage is approximately N.60°E. There are localities where it varies until it is due east, but these cases are exceptional. In a general way, the cleavage strike is more northerly in the eastern part of the region, more easterly in the western part.

The most noteworthy difference in cleavage between the eastern and western parts of the district, however, is in the dip. At Bangor and Pen Argyl the cleavage dip averages about 15°S.; at Wind Gap it is about 22°. At Danielsville the dip is approximately 45°, and at Slatington it is nearer 55°. There is thus a progressive steepening of the cleavage westward. The bearing of this on economical quarry development is discussed on page 30.

Curved cleavage. In a few places the cleavage surfaces of the slate are not absolutely flat. Thus, in the New Peerless (Bangor Vein) quarry individual blocks show a marked curvature, even in lengths of no more than six feet. The floors of the upper "pieces" in the Albion quarry at Pen Argyl are also not flat, but show gentle curves, actually dipping northward at low angles in the northeast part of the opening. Megascopic and microscopie examinations of the slate show no sign of undue strain; it therefore seems evident that this curvature originated during cleavage development, and not subsequently by lateral compression of the cleavage planes.

In other places the cleavage planes have clearly been compressed subsequent to their formation, yielding fracture cleavage (see page 35) through failure at angles inclined to the cleavage planes. The phenomenon is rarely seen east of Danielsville, but is common in the quarries at Slatington and Slatedale. It is not clear why there should be this marked difference in its distribution. There are several possible explanations but the most plausible seems to be that the compression producing this crinkling of the cleavage planes was from such an angle as to lie more nearly in the plane of the cleavage at Slatington than at Bangor and Pen Argyl. In view of what has already been said, this theory would make the later compression direction dip downward about 55° in a southerly direction; in other words, the thrust was perhaps northwestward and upward, not merely tangential to the earth's surface.

OTHER STRUCTURAL FEATURES.

Jointing. Joints are especially numerous near faults, particularly near bedding-slip faults. They do not clearly fall into definite systems, yet detailed studies show that, on the whole, the dominant trend is northeast.

False cleavage. This feature has already been referred to in connection with curved cleavage (See above). Most fracture cleavage planes strike roughly parallel to cleavage and bedding and dip steeply north or south.



A. Curved and irregular cleavage in big bed at trough of close fold in Albion quarry, Pen Argyl.



B. Folded cleavage in L. V. R. R. cut near Treichlers Station.

GEOLOGIC HISTORY

Study of the local stratigraphy and structural geology by the writer and many earlier geologists makes it possible to trace the development of the region during and since Paleozoic times.

After an uplift and a long period of erosion affecting the old, crystalline rocks of South Mountain, sands and limy muds were laid down in Cambrian and early Ordovician time. Sedimentation was intermittent, as shown by the fact that the sequence includes at least two noticeable unconformities. In Black River or early Trenton times, however, dark muds, rich in organic matter, began to accumulate at least in the northerly part of the counties here discussed. These organic muds were deposited immediately upon calcareous muds in most places, but locally they came to rest upon fairly well-consolidated limy sediments of earlier Ordovician or late Cambrian age. It is the deposition of these organic muds that inaugurated the period of sedimentation in which the Martinsburg was deposited.

The Martinsburg muds must have been laid down under special conditions. Their widespread distribution with relatively uniform lithologic features, the evidence of shallow water origin, the banded character leading to the inference of periodic, perhaps seasonal fluctuations in conditions of sedimentation, the general lack of fossils (a fact suggesting scanty life), the unidirectional cross-bedded and locally ripple-marked character pointing toward moderately strong, uniform currents,—these are features not easily placed in mutual agreement. The evidence given and the consensus of opinion appear to favor the idea that the Martinsburg sediments were deposited in quiet estuaries or embayments and for the purposes of this report the statement may be accepted without further discussion.

Following widespread sedimentation the land was uplifted and the rocks were folded, at least to a moderate extent, and with their conversion to shales and finally into slates the sediments had impressed upon them a definite slaty cleavage. This folding, coincidental with uplift, resulted in considerable erosion of the Martinsburg. Subsequently the Martinsburg beds, now channeled and truncated by erosion, were once more submerged, and new sediments of a sandy and gravelly nature were laid upon them. These represent the inauguration of Tuscarora (Medina) deposition. Upon them in turn were laid down still other materials, now worn completely away from this region. Finally sedimentation was brought to a close by compression and uplift that, though it followed the same trend-lines as the folding at the close of the Martinsburg, was much more intense, threw all these previously mentioned rocks into flexures, further folded the cleavage already present in the Martinsburg formation, and was accompanied or shortly followed by thrust and normal faulting. This revolution closed the chronologic division referred to by geologists as the Paleozoic era.

A long succeeding time interval, the Mesozoic era, during which erosion and possibly repeated gentle uplifts were the only conspicuous processes, elapsed. Later geologic time (the Tertiary period) witnessed similar gentle uplifts and continued erosion, and it was during the Mesozoic and Tertiary that the several conspicuous erosion levels—the Kittatinny, Schooley, and most of the later “peneplains,” already mentioned—were developed.

During the Pleistocene or "Great Ice Age," glaciers came down from the north, wearing away smaller projections on the land surface and depositing a great deal of material, or causing deposition in stream valleys by overburdening with pulverized rock the streams that flowed out southward from beneath the ice. Where the ice front stood for several years, the material which the advancing ice pushed forward to its terminus accumulated into a noticeable ridge or succession of ridges,—the terminal moraine; an example is that from Pen Argyl to Belvidere, already mentioned. In most places, however, the ice-borne rock was more evenly distributed over the ground, so that the effects of glaciation are not so striking, though still recognizable. It is possible that the glaciers advanced into this part of Pennsylvania and retreated again northward between advances at least three separate times, an appreciable time elapsing between the preceding and each fresh advance.

The subsequent history after glacial retreat is chiefly one of erosion,—the slow decay of surface rock through atmospheric action, the gradual wearing away by solution and abrasion of water running in streams, and the local deposition of the stream-borne material as bars or other floodplain deposits. Locally also, along the south edge of Blue Mountain, thick deposits of angular rock pieces, breaking and falling from the quartzite cliffs that crown the mountain ridge, have accumulated on the slate terrace below. These are mainly if not wholly of recent origin, postglacial in time.

COMPOSITION OF THE SLATE

CHEMICAL COMPOSITION

There is no great difference between the chemical compositions of the various types of slate in the Lehigh-Northampton district. The following table furnishes a basis for comparison. Attention may be directed to a few special features.

The average silica content lies between 56.5 and 57.5 per cent. Differences reflect, in a measure, not merely variations in quartz content, but also in the mica present; a slate high in silica contains relatively large amounts of quartz and mica; conversely, if it shows relatively little silica its calcite content is relatively high.

Differences in silica content are likely also to be correlated with variations in hardness. Typical "hard" belt slates are especially high in silica, containing 60 per cent or so. Conversely exceptionally "soft" slates generally bear not much over 55.5 per cent; electrical slate is also usually low in silica.

Titanium oxide varies from 0.35 to 0.85 per cent; alumina also is highly variable. These two constituents are not clearly related to any special qualities. Iron oxide content seems to fluctuate similarly to the lime content, as a rule, being greater when the latter increases, a fact which supports Dale's contention that the iron occurs as a carbonate isomorphous with calcite. The dominance of calcium over magnesium and of potassium over sodium is marked.

Sulphur and carbon are highly variable. Carbon is most prominent in the dark beds or "ribbons." The sulphur is chiefly in the form of pyrite; contrary to what might be expected, it does not appear to be especially prominent in the exceptionally dark beds.

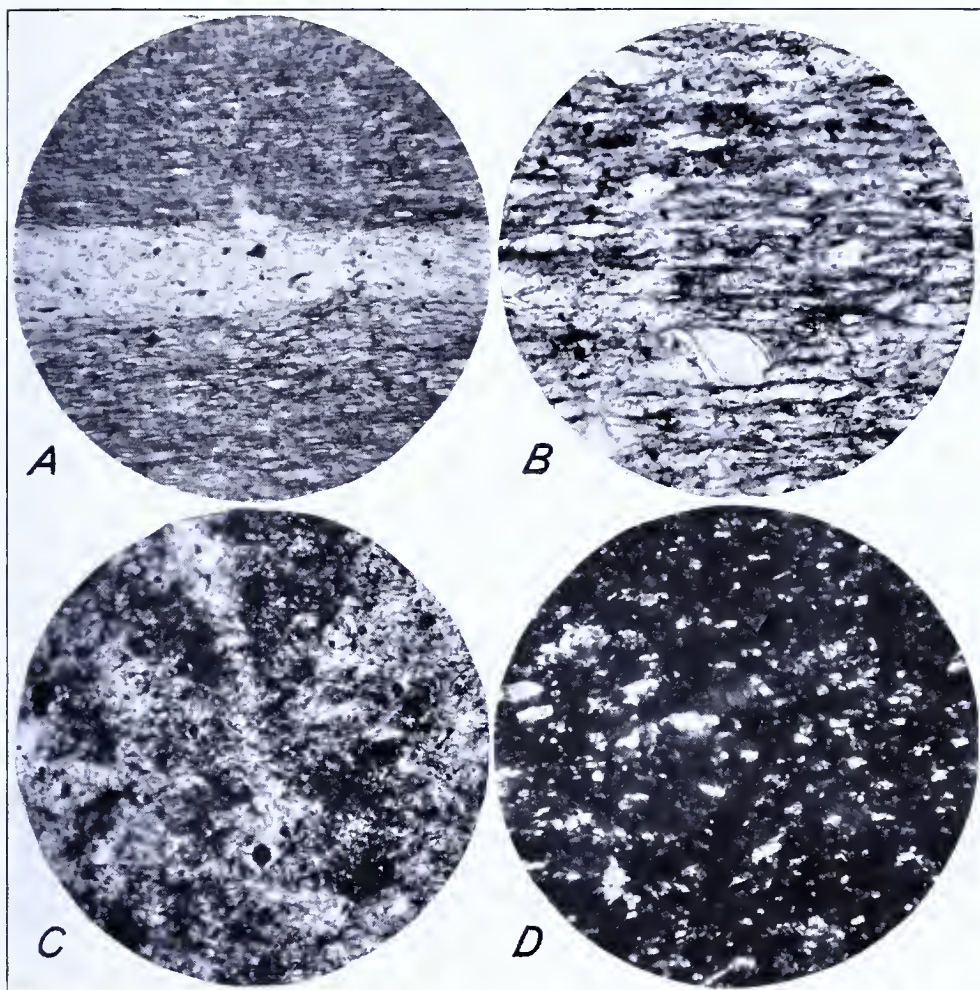
Analyses of slates from Lehigh-Northampton districts.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| SiO ₂ ----- | 56.85 | 56.38 | 57.10 | 57.30 | 68.62 | 57.14 | 55.56 | 57.50 | 55.32 | 55.56 | 64.52 | 59.67 | 58.50 | 54.56 | 55.10 | 60.22 |
| TiO ₂ ----- | 0.54 | 0.78 | 0.45 | 0.36 | n.d | 0.53 | 0.66 | ----- | 0.89 | 17.32 | 0.49 | 0.40 | 27.60 | 0.83 | 0.88 | 19.56 |
| Al ₂ O ₃ ----- | 15.24 | 15.27 | 21.05 | 21.45 | 12.68 | 17.08 | 20.57 | 20.84 | 20.01 | ----- | 16.84 | 21.97 | ----- | 16.47 | 18.95 | ----- |
| FeO-Fe ₂ O ₃ ----- | 5.52 | 4.90 | 3.40 | 3.58 | 4.20 | 5.76 | 6.18 | 3.51 | 5.13 | 6.94 | 4.31 | 4.24 | 1.45 | 7.15 | 3.75 | 5.24 |
| CaO ----- | 4.24 | 4.23 | 3.86 | 3.85 | 1.31 | 3.95 | 3.27 | 3.92 | 2.21 | 6.06 | 2.21 | 1.15 | 0.88 | 4.46 | 2.88 | 3.87 |
| MgO ----- | 2.93 | 2.84 | 3.10 | 3.15 | 1.80 | 3.29 | 2.76 | 3.02 | 3.63 | 2.79 | 2.94 | 3.46 | 2.42 | 2.90 | 3.06 | 2.30 |
| K ₂ O ----- | 2.34 | 3.51 | 3.27 | 3.32 | 3.73 | 3.11 | 2.95 | 3.36 | 3.67 | 3.13 | 3.42 | 2.83 | 3.42 | 5.12 | 3.32 | n.d |
| Na ₂ O ----- | 1.38 | 1.30 | 1.31 | 1.28 | ----- | 1.05 | 1.12 | 1.25 | 1.84 | 2.23 | 1.76 | 0.91 | 3.41 | 1.96 | 1.28 | n.d |
| CO ₂ ----- | 3.58 | 3.67 | 3.30 | 3.40 | 2.99 | n.d | n.d | 3.30 | n.d | n.d | n.d | n.d | n.d | n.d | 3.15 | n.d |
| FeS ₂ ----- | 1.72 | 1.72 | 1.35 | 1.42 | n.d | n.d | n.d | 1.39 | n.d | n.d | n.d | n.d | n.d | n.d | 1.62 | n.d |
| S ----- | n.d | n.d | n.d | n.d | n.d | n.d | 1.84 | n.d | 0.76 | 0.88 | 0.35 | 0.23 | 0.23 | 0.87 | n.d | n.d |
| C ----- | n.d | 0.59 | 0.60 | 0.53 | n.d | n.d | n.d | 0.57 | n.d | n.d | n.d | n.d | n.d | n.d | 4.10 | n.d |
| Water above 110°C. -- | n.d | 4.09 | ----- | ----- | 4.47 | n.d | n.d | n.d | n.d | n.d | n.d | n.d | n.d | n.d | ----- | n.d |
| Water below 110°C. -- | n.d | 1.10 | ----- | ----- | n.d | n.d | n.d | 0.15 | n.d | n.d | n.d | n.d | n.d | n.d | ----- | n.d |
| Loss on ignition ----- | n.d | n.d | ----- | ----- | n.d | 9.75 | 9.50 | n.d | 6.85 | 7.02 | 4.37 | 9.73 | 4.65 | 6.76 | ----- | 7.45 |

n.d.—Not determined.

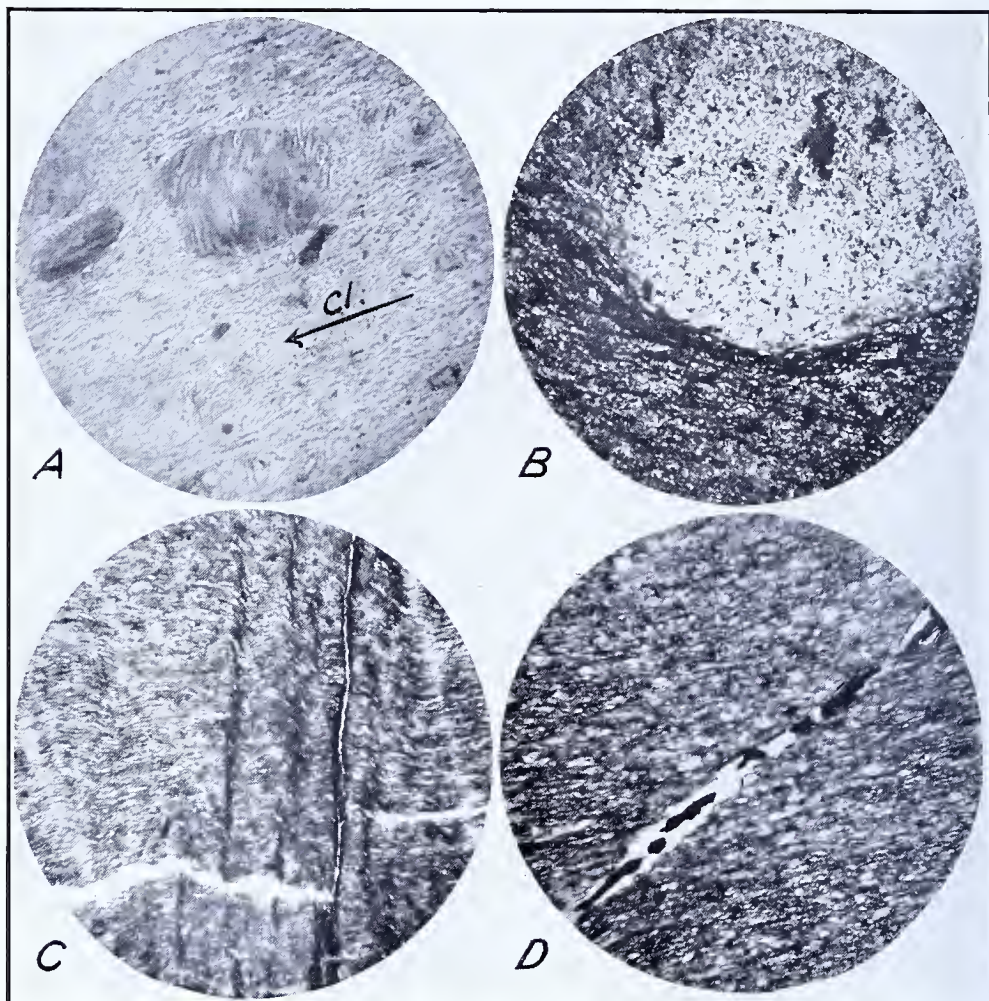
- 1.—Lower Washington big bed, Hazel Dell quarry, Slatington; U. S. Geol. Survey, Bull. 275, p. 84. W. F. Hillebrand, U. S. Geol. Survey, analyst.
- 2.—Lower Franklin big bed, Franklin quarry, Slatington; U. S. Geol. Survey, Bull. 275, p. 84. W. F. Hillebrand, U. S. Geol. Survey, analyst.
- 3.—A bed at Bangor; Resistivity of slate against acids and alkalis, privately published. Robt. Notvest and H. S. Booth, analysts.
- 4.—A bed at Wind Gap; Resistivity of slate against acids and alkalis, privately published. Robt. Notvest and H. S. Booth, analysts.
- 5.—A bed from Consolidated No. 1—Star quarry, East Bangor; U. S. Geol. Survey, 20th Ann. Rept., Pt. VI (2), p. 436, 1899. W. F. Hillebrand, U. S. Geol. Survey, analyst.
- 6.—A bed of exceptionally hard slate from Consolidated No. 1—Star quarry, East Bangor; M. K. Buckley, Lehigh Univ., analyst.
- 7.—A bed of exceptionally soft slate from Consolidated No. 1—Star quarry, East Bangor; M. K. Buckley, Lehigh Univ., analyst.
- 8.—Electrical slate, Structural Slate Co., Pen Argyl; N. V. Anderson, Lehigh Univ., analyst.
- 9.—Electrical slate, Stephen Jackson Co., Pen Argyl; M. K. Buckley, Lehigh Univ., analyst.
- 10.—Electrical slate, Shenton quarry, Lynport; C. L. Lancaster, Univ. of Cincinnati, analyst.
- 11.—The Pen Argyl Gray bed, Thsman quarry, Wind Gap; M. K. Buckley, Lehigh Univ., analyst.
- 12.—The Bangor Gray bed, Columbia Bangor quarry, Bangor; M. K. Buckley, Lehigh Univ., analyst.
- 13.—The Gray bed, Columbia Slate Co. quarry, Slatetale; C. L. Lancaster, Univ. of Cincinnati, analyst.
- 14.—A black "ribbon", Albion quarry, Pen Argyl; M. K. Buckley, Lehigh Univ., analyst.
- 15.—A black "ribbon", Resistivity of slate against acids and alkalis, privately published. Robt. Notvest and H. S. Booth, analysts.
- 16.—Typical "hard" belt slate from quarry at Huckleberry Ridge near Jordan Church; C. L. Lancaster, Univ. of Cincinnati, analyst.

PLATE 37.



Photomicrographs of slate from Lehigh-Northampton district. A. "Hard" slate, cut at right angles to cleavage, from Roth quarry, one mile east of Scheidy; note quartzose bed or "ribbon" between sericitic slate, and approximate parallelism between bedding and cleavage, as shown by elongation of light-colored (quartz) particles; x 50 diams.; B. Typical "soft" slate, cut at right angles to cleavage, from Consolidated-Star quarry, Bangor; the large lens is a chlorite porphyroblast; smaller clear areas are quartz lenses; note graphite spherules; x 200 diams. C. Same as last, but in plane of cleavage; note graphite spherules and absence of parallelism in orientation; D. "Hard" slate from Snyder'sville quarry of Walberts group, cut parallel to cleavage, seen under crossed nicols; the light particles are carbonate, elongated somewhat in direction of the grain; x 150 diams.

The various light olive-gray beds called Gray beds are exceptions to some of the preceding generalizations. In comparison with the slates of the Lehigh-Northampton district that show the "blue-gray" color more usual in such rocks, the Gray beds are relatively rich in silica and, in at least two analyses, unusually high in the alkalies taken together, while relatively lean in the alkaline earths and especially in iron; finally, though this is not demonstrated by chemical analysis but rather by petrographic examination, the Gray beds are exceptionally



Photomicrographs of slate from Lehigh-Northampton district. A. Gray bed from Consolidated-Star quarry, Bangor, cut at right angles to cleavage; note chlorite porphyroblasts, with cleavage at right angles to slaty cleavage (Cl) of ground mass; x 200 diams. B. Soft slate from Montgomery quarry, Dautelville, cut parallel to cleavage; light area chiefly quartzose; note crowding aside of ground mass showing typical slaty texture on edge of knot; x 16. C. "Soft" slate, cut across the cleavage; shows false cleavage, in part with actual fractures; x 42; D. Soft slate from Consolidated No. 3 quarry, Bangor, at right angles to cleavage; to show joint filled with calcite (white) and pyrite (black); x 60.

low in carbon. The absence of lime, magnesia, and iron probably accounts for the fact that color-changes and weathering are even more gradual than with the average of the other slates. In general, the chemical composition of the Gray beds strongly resembles that of the "unfading green" slates of Vermont.¹

MINERALOGICAL COMPOSITION

Studies with the petrographic microscope are, in general, more satisfactory than chemical analyses in determining the quality and

¹ Dale, T. N., and others, *Slate in the United States*: U. S. Geol. Survey, Bull. 586, p. 51, 1914.

possible uses of a slate. In the course of this work the writer examined 64 thin sections of slate samples collected by him in the Lehigh-Northampton district, together with 35 others, made available through the courtesy of the Curator in Geology of the U. S. National Museum.

Sections studied were chiefly either oriented at right angles or parallel to the cleavage plane. Of these the latter yielded more information regarding the constituents, as they usually show basal pinacoids of the minerals to be identified. In sections at right angles to the cleavage, on the other hand, fibers of muscovite and less commonly of chlorite, and grains of quartz, calcite, and chlorite are observed, all generally elongated parallel to the cleavage; they thus afford the best picture of the structural relations of the minerals.

Minerals of the slate. Named in the order of their quantitative importance, the minerals observed include muscovite (sericite), quartz, calcite (probably bearing some magnesia and iron),¹ chlorite, graphite, pyrite, rutile, biotite, magnetite, plagioclase, and zircon. The last two are rare. A mineral of the kaolin group appears to be present, but the species could not be identified with certainty on account of the small size of the particles.

Probably the outstanding mineralogical characteristic of the slates of this district is the relatively large amount of carbonate (especially calcite) present. How much of this is primary is not certain; evidence has already been adduced² to show that some, at least, is secondary in the case of the slates of Bangor and Pen Argyl and similar observations have more recently been made in connection with the slates of Danielsville, Slatington, and Slatedale. The only type of slate studied microscopically in which the relative importance of carbonate was not observed is that represented by parts of the so-called Gray beds at Bangor, Pen Argyl, Danielsville and Slatedale.

So similar mineralogically are the various slates that a general description of their mineral content may be given.

Quartz.—In ellipsoidal grains averaging 0.025 mm. in diameter, and seldom attaining 0.10 mm. They are generally larger in the "soft" than in the "hard" slate and reach maximum sizes in the "hard rolls" or sandy layers at the base of the thicker slate beds. The fineness of some of the smaller grains is amazing and the total absence of grains with diameters as large as 0.75 mm. is striking, in view of Ziegler's³ assertion that this is the minimum size for effective abrasion in water. As these grains generally lack angular faces, the inference may well be that they were blown, rather than carried by streams, into the waters of the Martinsburg seas.

Most quartz grains have no dihedral angles, being moderately or well rounded, but a few, especially the largest, still show pronounced crystal angles. In sections perpendicular to the cleavage the rounding of the corners is more pronounced, yet even here occasional grains are sharply angular. Occasionally the shapes are highly irregular, having been "eaten into" by advancing secondary calcite, as discussed below (page 179).

Dimensionally the quartz grains are ellipsoids, with three unequal axes, the longest and shortest lying in the grain plane with the longest parallel to the cleavage and the shortest at right angles to it. The average ratio of greatest to least dimensions is approximately 2:1. Some grains are very slender with ratios varying all the way up to 5:1, and these exceptional forms owe their disproportionate length almost surely to secondary growth. Indeed, almost all of the marked differences in dimensions should probably be attributed to metamorphism.

¹ Dale, T. N., and others, op. cit., p. 56, 1914.

² Behre, C. H., Jr., *Slate in Northampton County, Pennsylvania*: Pa. Top. and Geol. Survey, Bull. M 9, pp. 80-82, 1927.

³ Ziegler, Victor, Factors influencing the rounding of sand grains: *Jour. Geol.*, vol. 19, p. 654, 1911.

Most of the quartz grains show faint strain shadows. In places they are aggregated to form siliceous "knots" described elsewhere (see page 17). Individually the grains are generally clear. Inclusions are relatively few. Apatite prisms are the most common.

In addition to the quartz grains with definite boundaries already discussed, there are areas or masses bearing cloudy quartz full of inclusions, especially of rutile needles. These are thought to represent secondary quartz, of the age of that just mentioned as having contributed to the elongation of distinct particles of this mineral, but, unlike the latter, not laid down around a quartzose center. This cloudy quartz is so completely intergrown with the other minerals making up the slate that it can scarcely be resolved under the microscope and is not subject to detailed study.

In the aggregate these two types of quartz vary in quantity with the hardness of the slate. In some finely banded slates, notably in those of the "hard" belt, individual layers are seen under the microscope to be richer in quartz, especially the granular type, and they evidently represent sandy beds.

Muscovite.—This term is used here for white mica in general without wishing to distinguish between primary and secondary mica, nor to raise the question whether the mica is a true muscovite or one of the closely related isomorphous mixtures recently described by Winchell;¹ the chemical analyses of the slates strongly suggest the presence of appreciable quantities of soda in the mica molecule, the ratio of soda to potash approaching 1:3.

The mineral assumes two forms.—first, relatively rare single flakes, of which the longest dimension is to the shortest in the ratio of 2:1 or more; and second, very thin, hair-like strands weaving in sinuous lines around the more granular minerals and forming the larger part of the body of the rock.

The flake type is in shred-like crystals the average smaller diameter of which is about 0.005 mm. It is clear, without inclusions or halos of any kind. There is a very faint greenish pleochroism, and the mineral as usual has the greatest relief parallel to the maximum dimensional elongation. In the cleavage plane, the mica flakes are generally virtually basal sections, and hence are scarcely visible under crossed nicols, even if turned 45° from the position of extinction, but in planes at right angles to the cleavage they show as brightly colored shreds with high birefringence. Dimensionally they are greatly elongated in the direction of the grain, and somewhat less so in the plane of the cleavage and in that at right angles to both cleavage and grain. This type of mica has, on the whole, fair aggregate extinction parallel to the grain direction.

The fibrous type of muscovite grades into the flake type by progressive reduction of the lesser dimensions. It has exceptionally good aggregate extinction, and evidently determines the cleavage. Its dimensions in directions other than its maximum are (in comparison with the length) so slight as to be negligible, the individual shreds frequently appearing virtually as dark, hair-like bands and only distinguishable as crystals under highest magnification. Unlike the flakes already described, this form of mica is curved in sinuate lines to adjust itself to the more equidimensional mineral grains, notably quartz and carbonate, so that the texture suggests somewhat that seen in porphyritic igneous rocks and termed trachytic. In the so-called Gray beds, the fibers are wider, but still have the same sinuousness and great length as in the more common slate varieties.

Calcite (?).—This mineral shows chiefly as rhombs and irregular masses, the latter especially where replacing quartz. Its maximum dimensions are 0.01 mm., but the particles vary to sub-microscopic size and there is no uniformity whatever. In the plane of the cleavage the mineral grains are approximately rhombic and equi-dimensional, with a slight tendency toward elongation in the direction of the grain. In sections at right angles to the cleavage, the elongation is largely parallel to the cleavage, with a very faintly noticeable aggregate polarization.

When fresh and unweathered the mineral appears very clear under the microscope, with only rare inclusions of rutile and graphite. As soon as weathering sets in, however, the spots of calcite assume a rusty color. This

¹ Winchell, A. N., Studies of the mica group—Part II: *Am. Jour. Sci.*, ser. 5, vol. 9, pp. 419-424, 1925.

fact lends support to the contention of Dale and Hillebrand¹ that the common carbonate in slates is an isomorphous mixture of lime, iron, and magnesia, for oxidation would then produce discoloration of the iron compound, giving yellowish rusting.

One striking observation in connection with the occurrence of the carbonate is its common replacement of other minerals. Throughout all the slate examined, it is apparently largely secondary to the quartz, especially to the lenticular forms of the latter; in such instances replacement has generally been most effective at the ends and edges of the quartz grains, especially where they taper to relative narrowness (see figure 55).

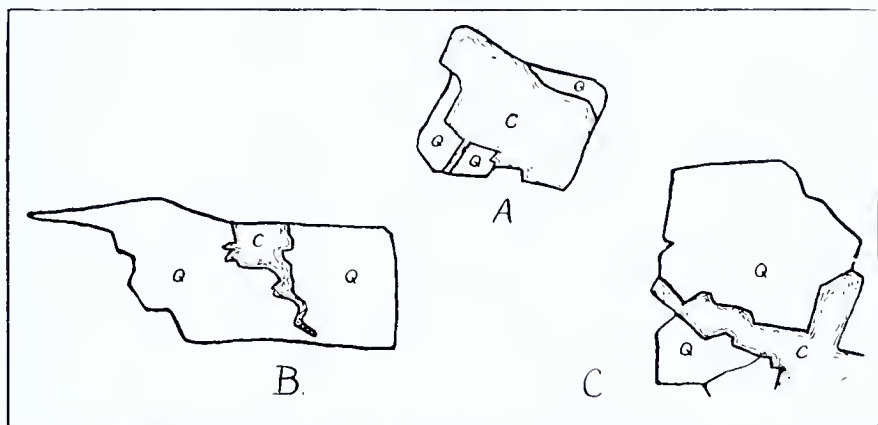


Figure 55. Microscopic grains of quartz (Q) replaced (A and B) or with crevices filled by secondary calcite (C); in each case all of the quartz is part of one crystal. Thin section of slate from New Diamond quarry, Pen Argyl, x 350.

In places the carbonate has attacked and replaced the central part of a quartz grain, commonly along a fracture, and the two quartz remnants, now separated, show simultaneous extinction and similar orientation; thus it is clear that the calcite is the secondary mineral. In a few instances feldspar grains occur like the quartz and have also been replaced by the calcite, but to a lesser degree; this, too, goes to show that the carbonate is the later mineral, for the replacement of calcite simultaneously by feldspar and by quartz is scarcely to be expected.

Chlorite.—Like the muscovite, chlorite assumes two forms. One of these consists of slender flakes scattered through the greater part of the rock and making up its background. The quantity of chlorite as distinct from muscovite in this form is difficult to estimate on account of the fineness of grain and the close intergrowth of most of the mineral constituents. Its presence can only be verified here and there by a faint greenish pleochroism or by the characteristic unusual blue-gray interference colors.

The other form in which the chlorite occurs is as flakes or grains. In size these equal or exceed the largest grains of other mineral species found in the rock. They are roughly rectangular or elliptical in all sections and have a maximum diameter of about 0.16 mm.; the average of the greater dimensions is approximately 0.060 mm. Ratio of length on the one hand to width and thickness on the other is generally about 3:2, but sections at right angles to the cleavage show greater differences between the two dimensions than those in the cleavage plane. On the whole, however, this form of chlorite gives the impression of very largely lacking orientation. Similarly unoriented grains—in this case feldspar—have been described by Dale in Ordovician schists from Dorset, Vermont;² mica, likewise unoriented and closely resembling the

¹Dale, T. N., and others, *Slate in the United States*: U. S. Geol. Survey Bull. 586, p. 18, 1914.

²Dale, T. N., *Structural details in the Green Mountain region and in eastern New York*: U. S. Geol. Survey Bull. 195, pp. 16-17, 1902.

chlorite in the slates of the Lehigh-Northampton district, is also described and figured by Born¹ from the lower Devonian slates of the Eifel region, Germany.

These poorly oriented chlorite individuals generally show mineral cleavage extending more or less at right angles to the cleavage of the slate. In addition to a very poorly marked approach to dimensional orientation in the chlorite, there is thus also a mineralogical orientation (as expressed by the cleavage) which is not only not definitely parallel to the mineralogical orientation of most of the other minerals in the slate but is, on the contrary, decidedly at variance with the latter. In many instances such cleavage has been distorted, twisted or bent, or is inclined to the plane of the slaty cleavage (see Figure 56); these features all suggest deformation by shear or compression.

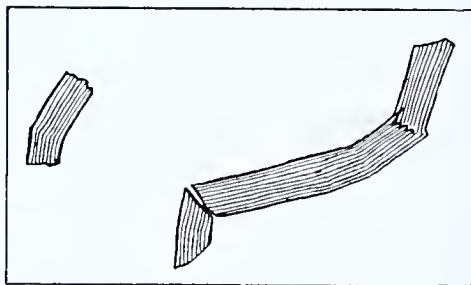


Fig. 56. Bending and fracturing in microscopic flakes of secondary sericite. Thin section of slate from New Diamond quarry, x 350.

It is difficult to understand, however, how the original mineral cleavage of the chlorite came in the first place to be mineralogically oriented at so great an angle to the orientation of the muscovite and calcite if its origin is to be traced to metamorphic growth. Possibly the chlorite crystals may be regarded as porphyroblasts,² though Born maintains the similar mica grains to be different³ from true porphyroblasts.

On the whole, this kind of chlorite crystal is free from inclusions. It is a light green mineral, with light green to white pleochroism. A striking feature is the occurrence here and there within the mineral of very faintly brownish areas showing interference colors of a high order, and parallel extinction, and thus suggesting biotite. It is altogether possible that these represent, therefore, biotite swept into the Martinsburg seas by sedimentation and, in the process of metamorphism, converted to chlorite. Elsewhere thin stringers of a mineral cross the chlorite which resemble these biotite remnants in all respects except in color, being virtually colorless; whether these are to be looked on as muscovitic alterations of the chlorite (which was the first interpretation offered),⁴ or as sedimentary biotite that has been bleached, is still uncertain. The writer inclines to the interpretation already suggested,—that the chlorite is porphyroblastic and the mica borders and strands are a later alteration product.

Rarely faint limonitic halos surround the biotite(?)—chlorite lenses and an occasional carbon grain is found in them also.

Graphite.—Carbon, probably graphitic, occurs in two forms,—spherical blotches, about 0.015 mm. or less in diameter, and irregular amorphous masses up to 0.10 mm. in largest dimensions. The latter are relatively rare. They are most common in the carbonaceous “ribbons” and frequently give the appearance of remnants of organic matter; thus, in slate from the Ontelaunee quarry the outlines are commonly curved, sometimes resembling complete ellipses, though such definite forms are generally lacking. Locally the graphite constitutes masses with crenate edges, surrounded by halos of clearer

¹ Born, Axel, *Über Druckschieferung im Varistischen Gebirgskörper*, Plate II, 7 and pp. 356-357, Borntraeger, Berlin, 1929.

² Grubenmann, U., and Niggli, P., *Die Gesteinsmetamorphose*, pp. 466-469, Borntraeger, Berlin, 1924.

³ Born, Axel, *op. cit.*, p. 356.

⁴ Behre, C. H., *Slate in Northampton County, Pennsylvania*: Pa. Top. and Geol. Survey, Bull. M-9, pp. 78-79, 1927.

matter, which suggest purification of the beds through the segregation of the carbon around a central nucleus.

The spherical type is aggregated into clusters varying greatly in size or occurs as spherules, up to 0.01 mm. in diameter, scattered as isolated individuals through the slate. It is this type that determines the relative darkness in the color of the slate. Locally larger areas, up to several inches in size, are highly crowded with such spherules, forming the carbon "knots" so objectionable in electrical slate.

Pyrite.—Rarely this occurs in lenses and as filling of veinlets. More commonly it forms irregular masses or spherules, not readily distinguishable from the graphite spherules except where weathered. In many places it, like graphite, forms the centers of chlorite lenses. Like graphite also, pyrite appears to be more common in the darker "ribbons."

Rutile.—In very tiny, almost sub-microscopic needles, locally well oriented so as to have maximum elongation parallel to grain. Their origin is probably secondary, as they appear as inclusions associated only with secondary minerals.

Biotite.—This occurs rarely, and was seen only in association with the chlorite grains mentioned above, which indeed may possibly be altered biotite flakes. The original presence of biotite (now greatly altered) in these cases is suggested by the faintly brownish tint of some of the chlorite, the local traces of high birefringence, and the mottled extinction, similar to that of biotite.

Magnetite.—In small grains, commonly included in the chlorite. Though occurring in most thin sections, it represents only a small part of the mineral constituents.

Plagioclase.—Rare small grains of plagioclase, greatly weathered and evidently an original sedimentary constituent, are seen, especially in the more sandy layers. Their sizes approximate those of the quartz grains. Albite twinning lamellae are faintly visible, but there is not sufficient uniformity to determine the composition of the plagioclase. Being sedimentary grains brought together from several sources, they may be expected to vary between the possible extremes of albite and anorthite.

Zircon.—In rounded grains, rarely seen, averaging .04 mm. in diameter. The mineral is evidently sedimentary in origin and is most common in the sandy layers.

Tourmaline.—Reported by Dale,² in similar slates from Dauphin County, but not found by the writer in the slates of this district.

Kaolin.—Probably present, but not positively identified.

Limonite.—This occurs as an alteration of pyrite and of the carbonate ("calcite"?) in the zone of weathering. It is not a primary constituent of the slate.

Late metamorphism. In an earlier bulletin³ it has been shown that most, if not all, of the calcite (?) mentioned above is due to a late period of metamorphism in which waters saturated with carbonates attacked and replaced especially the quartz grains (see Figure 55). This chemical effect may have accompanied the physical deformation of secondary muscovite, locally observed in the slate (see Figure 56), but the simultaneity of the two processes is debatable.

¹ See also Dale, T. N., op. cit., p. 18.

² Op. cit., p. 109.

³ Behre, C. H., Jr., *Slate in Northampton County, Pennsylvania: Pa. Top. and Geol. Survey Bull. M-9*, pp. 80-82, 1927.

CHEMICAL AND MINERALOGICAL
CHARACTERISTICS OF SPECIAL TYPES OF SLATE**HARD SLATE.**

Several thin sections of hard slate from quarries in the Lehigh-Northampton district were examined microscopically. Very few large grains of quartz are in evidence, and much of the groundmass is amorphous or so finely crystalline that under the crossed nicols the brilliantly colored calcite and muscovite stand out sharply from the dense, colorless background. In sections at right angles to cleavage, the flakes of mica have an arrangement faintly suggesting fluidal texture. Bands of darker material, evidently more carbonaceous beds, cross the field, and are separated by a width of lighter colored matter; the dark bands differ only in containing a larger number of carbon masses. The light bands consist of muscovite, quartz, carbon, calcite (?), chlorite, rutile, and plagioclase. A typical analysis is Number 16, under "Chemical Composition," on page 174.

SOFT SLATE.

Typical slate of the big beds. Sections show exceptionally uniform size of the grains, a feature which may well account for the perfect cleavage and excellent grade of the slate as electrical material. The section parallel to the cleavage exhibits medium-sized grains of calcite, quartz, muscovite, and chlorite in a rather dense groundmass, not resolvable into its constituents even with strong lenses. The slate is darkened by the presence of rutile needles and of graphite. Percentage composition of chief constituents is approximately muscovite 20, chlorite 20, calcite 15, quartz 10, and groundmass and minor constituents 35.

Harder and softer beds compared. At the Consolidated No. 1-Star quarry, two specimens were selected by the quarrymen to compare a very soft with a very hard bed in the slate. Microscopic study of sections parallel to the cleavage show that the soft slate differs from the harder in the following:

1. The chloritic and muscovitic bands along which the slate cleaves are more closely spaced in the softer slate.
2. The individual grains are smaller in the soft slate than in the harder slate.
3. The total volume of quartz in proportion to the other constituents is less and that of chlorite and calcite more in the softer slate.

A similar question was faced by Dale,¹ who concluded, from studies in the slate belt of Vermont, that the relative "softness" of some slates was to be attributed to their greater percentage of carbonate and to the smaller size of the individual quartz grains, rather than to the lower percentage of silica.

Chemical analyses of each of these two specimens (see Analyses 6 and 7, under "Chemical Composition," above) show that silica content is higher in the harder slate.

¹ Dale, T. N., The slate belt of eastern New York and western Vermont: U. S. Geol. Survey 19th Ann. Rept. part III, p. 245, 1899.

“Ribbons.” The darker beds or “ribbons” show textures varying from faintly to coarsely granular, the larger grains consisting of quartz, calcite, and muscovite. The composition is roughly: graphite 35 per cent, calcite 25, muscovite 20, quartz 10, indistinguishable groundmass 10. Graphite is especially common and largely obscures the field. Pyrite is also present in appreciable quantities. Chlorite is not conspicuous.

The description may be regarded as typical of all the “ribbons” of the soft slate examined. In sections inclined to the bedding, the lines separating alternating darker and lighter bands are very well marked. The bedding frequently is jagged and irregular, and small lenses of carbonaceous matter lie between less graphitic laminae.

The chemical composition of slate ribbons is given in Analyses 14 and 15. Noteworthy are the relatively high amounts of carbon, sulphur, and titanium oxide.

Gray beds. These are strata of olive-green color, rare in occurrence, exceptionally rich in chlorite and muscovite, and exceptionally lean in dark mineral matter.

A thin section of a specimen obtained from the Albion quarry at Pen Argyl and cut parallel to the cleavage was examined. The slate is exceptionally free from dark material, containing graphitic spherules in small quantity only. The texture is even and fine. The main constituents are present in approximately the following per cents: groundmass of chlorite and muscovite, 60; calcite (magnesia bearing), 15; quartz, 10; muscovite in flakes, distinct from the fibrous groundmass, 5; chlorite in large pieces, distinct from the fibrous groundmass, 5; minor constituents, 5.

Thin sections of the Gray beds at Bangor, Slatesdale, and Danielsville show no marked difference from that just described. In some sections quartz is in evidence and, though clear, without strain shadows, and uncorroded, shows much fracturing. Calcite is far more common in some sections than in the Gray bed of the Pen Argyl group.

The chemical composition of the Gray beds is illustrated by Analyses 11, 12, and 13, above. Especially noteworthy are the high silica and the low iron, lime, and sulphur contents. A part of the silica is unquestionably accounted for by the large amount of chlorite present. The analysis for carbon was not carried out; it would probably be low, to judge by the small amount of visible graphite in the thin sections.

Siliceous beds or “hard rolls.” A section from a “hard roll” in a Pen Argyl quarry is described below as typical of the petrography of such beds. The section is cut parallel to the cleavage. The texture is very coarsely granular in comparison with true slate, and shows what might be described as an arkosic quartzite rich in calcite, chlorite, and sericite. Rutile is conspicuously absent. Most of the definitely recognizable grains are 0.05 mm. or more in diameter. The approximate proportion of the constituents, as measured by a modified Rosiwal method, is quartz 30 per cent, calcite 25, graphite 15, chlorite 10, muscovite 10, feldspar 5, other constituents 5. From this list the dominance of granular minerals, as opposed to those possessing a definite axial elongation in one or more directions, is at once apparent.

Electrical slate. The conspicuous features of electrical slate are the fineness of texture and the uniformity in grain size. No single

crystal or fragment shows a diameter of over 0.1 mm. Even the quartz, the most coarsely granular of the constituents, rarely exceeds 0.06 mm. in diameter. Graphite, though present, is not conspicuous, and rarely forms large aggregates. These three features are most characteristic. A comparison of Analyses 8, 9, and 10, given above, suggests a slightly higher sericite content and a smaller quantity of pyrite than usual.

ECONOMIC GEOLOGY

SUMMARY

Although the "hard" slate of the Lehigh-Northampton district is essentially uniform throughout its thickness, the various beds of the "soft" slate are not all equally and uniformly workable. Some strata are valuable, whereas others are sheer waste. Such differences depend in part upon initial variations in the character of the sediments making up the slate. They are sufficiently marked and at the same time possess enough constancy in areal distribution to merit consideration only in the case of the "soft" slate.

In addition, the beds have been thickened or thinned through folding, and thus made relatively more or less valuable in differing places on the folds. Faulting has complicated their distribution, and minor structural features, such as joints, have introduced in different areas differing factors that alter from place to place the economy of working these deposits.

A consideration of these geologic factors that enter into the workability of the slates of Pennsylvania is the chief object of this report. For the Lehigh-Northampton district they are briefly listed and discussed in what follows.

In the region underlain by the "soft" slate, comprising the upper member of the Martinsburg formation, between Danielsville on the west and Wind Gap on the east, the development of the "soft" slate consists of only a few quarries, now long abandoned; stratigraphic sequence, structure, and technology differ somewhat east and west of this undeveloped region. Hence in discussing certain phases of geology and development it is best to separate these two sub-districts, a practice that will be followed in considering the detailed stratigraphy and the larger structures.

DETAILED STRATIGRAPHY OF THE SOFT SLATE

General considerations. As is well known to the slate operators, it is highly advantageous, other things being equal, to work thick, rather than thin beds. Hence it is desirable to know, especially in the "soft" slate of the Slatington and Pen Argyl-Bangor regions, what beds are available in a proposed plot of land or, in the case of a quarry already opened, how far the operator must go horizontally or vertically, with due regard to the angle of dip of the beds, before he will reach a desired thick or "big" bed. For these purposes, as well as for working out exactly the structure of the region, a detailed knowledge of the sequence of beds in the "soft" slate belt is indispensable. Much care was given, therefore, to thickness measurements, and the results are presented below.

Slate operators follow the practice of measuring slate beds by

"length," that is, of quoting the distance from top to bottom when measured along the "split," or cleavage. This value varies with two things, (1) the angle of intersection between cleavage and bedding and (2) the true thickness or shortest distance between top and bottom of the beds. Generally thickness gives a lower figure than "length," though rarely the values of the two are identical. Figure 18 shows how a bed having a constant thickness may vary in "length" with the angle of intersection of split and bedding. It should be clear that if the thickness is known, the "length" can be obtained by laying off the angle between split and bedding and reading the resulting distance (see Figures 24, 25, and 26).

As thickness is less variable than "length," the value of the former is given in the following tables leaving the reader to compute the "length" by the method just described.

Among slate operators it is customary to speak of closely associated beds as constituting "runs." Thus in one instance, there are two conspicuous beds, each about fifteen feet thick, separated by an approximately equal thickness of less massive beds. In the case cited the two thick strata are called the Upper and Lower Franklin big beds; hence, they, with the thin beds or "ribbons" that lie between them, are called collectively the Franklin "run." Though geologists do not use the term "run," its retention in this report is believed justified by popular practice.

Sources of error. Every effort was made to obtain accurate thickness measurements which, made in one or at best a few places, should be applicable elsewhere, with fair hope of correctness. It should be stated at once, however, that all such attempts to transfer the measurements made in one place to another locality are subject to grave errors, and hence that they should be applied with corresponding reservations. For this there are several reasons.

In the first place, not all of the beds are accessible: exposures are generally discontinuous and some of the strata that have been and in future will again perhaps be of economic importance are now covered by water or slate waste. Thus, the Upper Keystone big bed, once worked in the Keystone and other quarries, is now nowhere shown and no data as to its actual thickness or the aggregate thickness of the smaller beds separating it from the Lower Keystone big bed are available. For this reason its thickness is not separately listed in the table of thicknesses which follows. Again, the beds of the Columbia "run," though visible from the quarry walls, could not be actually measured; hence their thicknesses, too, are uncertain.

Second, due to folding, the beds thicken and thin greatly and average thicknesses are therefore arrived at with difficulty.

Third, as with all sediments, the individual strata, even before folding, varied somewhat in their original thickness from place to place.

Fourth, the figure for "average" thickness itself, when computed, generally introduces errors because of the limited number of observations upon which such an average is based.

Fifth, the folding is so close that a section measured down the dip cuts across beds with constantly changing dips; hence total thickness estimates almost always introduce errors of at least minor value.

The uncertainty in thickness estimates also, of course, carries with it a corresponding uncertainty in structural interpretation.

To reduce errors in individual cases the final thickness values given in the tables (and generally used in structural interpretation) represent, wherever possible, the average of several observations. The total of the average thicknesses of the "soft" slate beds measured near Slatington is 2,355 feet and near Pen Argyl and Bangor a minimum of 1,875 feet, as against a total of 1,529 feet arrived at by Sanders in his study of the slate belt.¹ The two figures are roughly comparable, especially in view of the fact that Sanders does not show at exactly what horizon his measurements begin.

Sequence in western part, Lehigh-Northampton district. In the following table the beds recognized by the quarrymen are given the names by which they are most generally known. The table indicates maximum and minimum observed thicknesses, as well as a value referred to as "average thickness", which generally represents an arithmetical mean of all observed thicknesses or gives what, in the best judgment of the writer, can be regarded as the usual thickness. In certain cases (e. g., the big beds of the Peach Bottom group) only one measurement of thickness could be made; in such cases the "average" thickness is the thickness actually measured, and maximum and minimum thicknesses agree, hence are omitted.

In a few instances so much uncertainty or variation exists in the thickness measurements of a bed or group of beds as to necessitate special mention. Thus, the full interval between the top of the Upper Franklin big bed and the base of the Lower Star big bed could be measured in only two places; one result gave 350 feet at the Bloos quarries west of Slatedale, where the strata were not actually exposed, and it was necessary to accept without further confirmation the statements of slate men as to the point of outcrop of the beds in question; the other gave 450 feet between the old Keystone and the Franklin Big Bed quarries along the Lehigh Valley Railroad at Slatington. An average value of 428 feet was finally taken, because data on more accurately measured parts of the sequence seemed to point to this as the most exact figure.

Uses of beds in western part of Lehigh-Northampton district. The most common use to which almost all of the thicker beds have been put is for roofing, there being still a large tendency on the part of the Slatington operators to give preference to roofing slate manufacture. In the Peach Bottom and Seagersville beds this use, as far as can be learned, absorbed practically all the production. The two big beds of the Blue Mountain "run" are suited for structural slate and blackboards; beneath these a conspicuously hard bed, which is about 6 feet thick and lying about 1 foot below the lower big bed of the Blue Mountain "run", shows low current leakage and thus is well adapted for electrical purposes.

The Trout Creek beds are not at present quarried; they were formerly worked primarily for roofing. Of the Penn Lynn series two of the thicker beds served for blackboards and one was used for roofing, but the production consisted largely of roofing slate from the smaller beds that lay between the large ones.

The Washington big beds east of Lehigh River, are used mainly for blackboards, but west of the river the lower bed is generally too full of

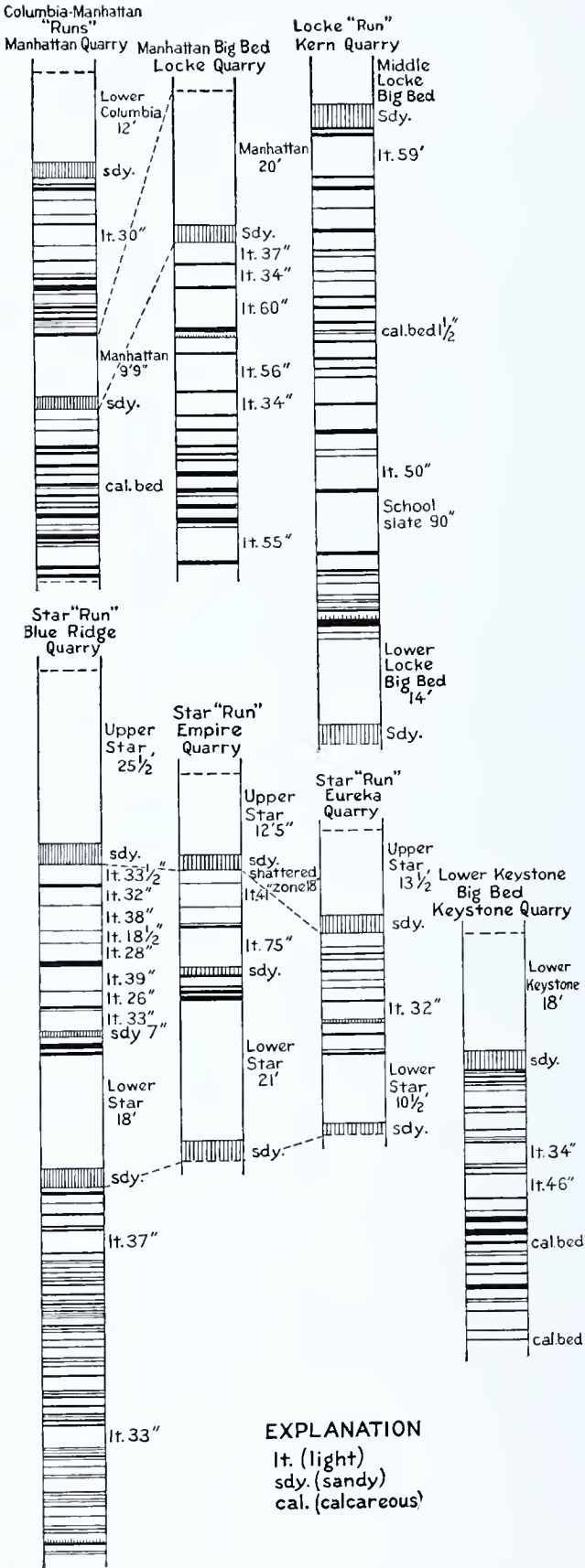
¹ Sanders, R. N., and others, *Geology of Lehigh and Northampton Counties; Pennsylvania*, Second Geol. Survey, D 3, vol. 1, p. 135, 1883.

Table of soft slate beds, western part of Lehigh-Northampton district.

| | | Thickness in feet | | | |
|---|--|-------------------|---------|---------|-----|
| | | Maximum | Minimum | Average | |
| Columbia
"run" | Upper Columbia big bed | 12 | 11½ | 12 | |
| | Intervening thinner beds | ? | ? | 30 | |
| | Middle Columbia big bed | ? | ? | 15? | |
| | Intervening thinner beds | ? | ? | 50 | |
| | Lower Columbia big bed | ? | ? | 15½ | |
| Locke "run" | Intervening thinner beds | ? | ? | 20 | |
| | Manhattan (Uppermost Locke) big bed | 20 | 9¾ | 15 | |
| | Intervening thinner beds | ? | ? | 100 | |
| | Second (Middle) Locke big bed | ? | ? | 14½ | |
| | Intervening thinner beds | 66 | 46 | 56 | |
| Star, Empire
or Eureka
"run" | First Locke (Klondike) big bed | 14½ | 10 | 12 | |
| | Intervening thinner beds | ? | ? | 45 | |
| | Upper Star (Empire, Eureka) big bed .. | 26¼ | 7 | 15½ | |
| | Intervening thinner beds | 24¾ | 17 | 16 | |
| | Lower Star (Empire, Eureka) big bed .. | 21 | 7 | 13 | |
| Keystone
"run" | Intervening thinner beds, including the
Fullmer "run" | | | | |
| | Upper Keystone big bed | 450 | 350 | 170 | |
| | Intervening thinner beds | | | | |
| | Lower Keystone big bed | | | | 18 |
| | Intervening thinner beds | | | | 165 |
| | Mammoth big bed | | | | 12½ |
| Franklin
"run" | Intervening thinner beds | | | | 62½ |
| | Upper Franklin big bed | 17 | 11 | 13 | |
| | Intervening thinner beds | 28¾ | 8½ | 19 | |
| | Lower Franklin big bed | 25½ | 10 | 16½ | |
| | Intervening thinner beds | 155 | 150 | 153 | |
| | Little Franklin big bed | 14 | 12 | 13 | |
| Washington
"run" | Intervening thinner beds | 109 | 65 | 87 | |
| | Upper Washington big bed | 47¼ | 10 | 20 | |
| | Intervening thinner beds | 19½ | 9 | 13 | |
| | Lower Washington big bed | 28½ | 9 | 16 | |
| | Intervening thinner beds including some
big beds in Penn Lynn "run" | ? | ? | 205 | |
| Trout Creek
"run" | Upper Trout Creek big bed | 24 | 19½ | 22 | |
| | Intervening thinner beds | 24 | 19 | 21 | |
| | Lower Trout Creek big bed .. | 19 | 17 | 18 | |
| | Intervening thinner beds | 350 | 290 | 320 | |
| Blue Moun-
tain "run" | Upper Blue Mountain big bed | 18 | 13 | 16 | |
| | Intervening thinner beds | 15 | 5 | 9 | |
| | Lower Blue Mountain big bed | 22 | 11 | 15 | |
| | Intervening thinner beds | 270 | 250 | 260 | |
| Saegersville
or Wil-
liamstown
"run" | Upper Saegersville (Williamstown) big
bed | 12¼ | 7½ | 9 | |
| | Intervening thinner beds | 8¾ | 4½ | 6 | |
| | Lower Saegersville big bed | 16 | 10½ | 14 | |
| | Intervening thinner beds | ? | ? | 195 | |
| Peach Bot-
tom "run" | Upper Peach Bottom big bed | ? | ? | 13½ | |
| | Intervening thinner beds | ? | ? | 13½ | |
| | Lower Peach Bottom big bed | ? | ? | 10½ | |
| Total thickness measured | | | | 2355½ | |
| Sandy beds of middle member of the
Martinsburg | | | | | |

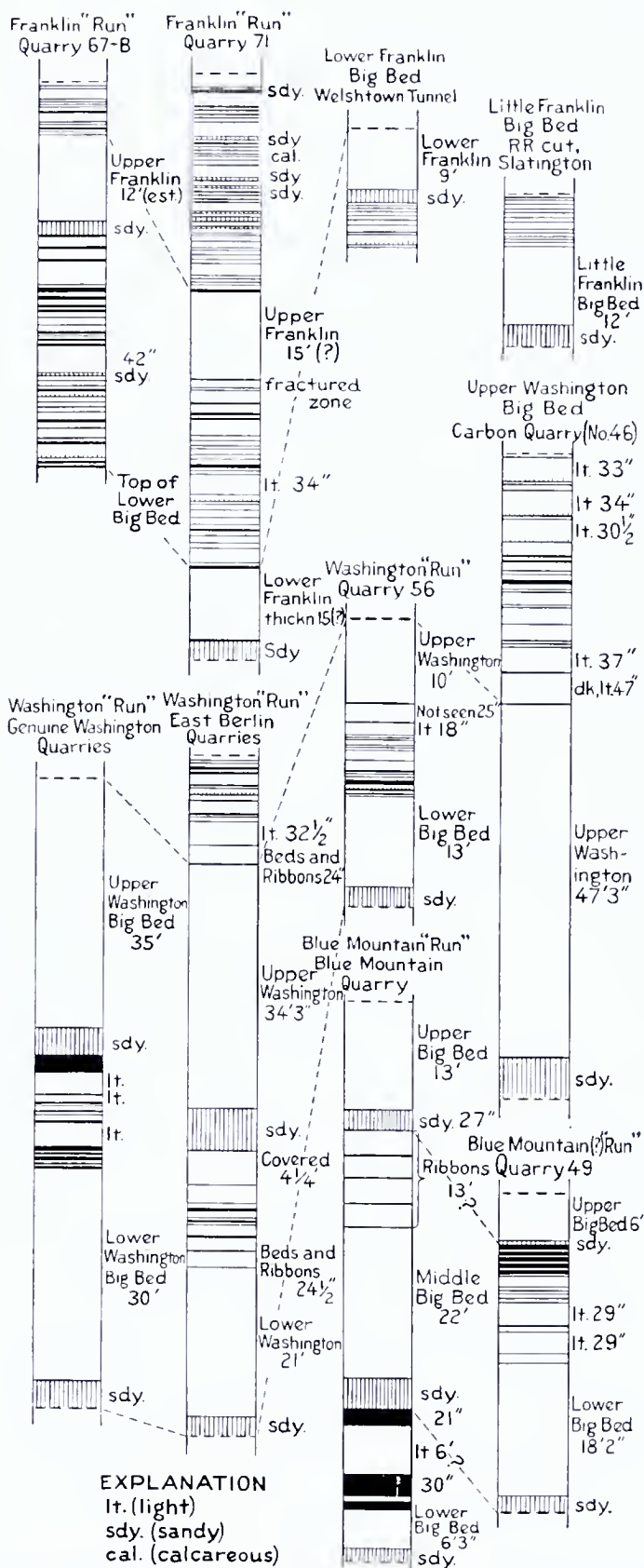
"knots" for this purpose. The upper bed is also utilized for electrical slate. Two black beds in the sequence, one under each big bed, yield good school slate material.

Of the Franklin beds, the lower is generally more valuable as it makes excellent blackboard slate. The upper bed can also be used locally but is not uncommonly spoiled by small, discontinuous joints. Both big beds are of course in demand for roofing.



Thickness measurements in beds at Slatington and Slatedale.
Scale 1 inch=200 inches.

PLATE 40.



Thickness measurements in beds at Slatington and Slatedale.
Scale 1 inch=200 inches.

The Little Franklin big bed, not at present quarried anywhere, was valuable for roofing and blackboards. A little above it a dark bed was even better adapted to the latter use. The Mammoth big bed, though a thick stratum, is too hard for most purposes and has generally been made into roofing slate.

The beds of the Star, Locke, and Columbia "runs" are said to be softer than those lower down in the sequence, in this respect suggesting strongly the Pen Argyl beds. They find their chief use in structural and roofing slate.

Sequence in eastern part, Lehigh-Northampton district. At Wind Gap, Pen Argyl, and Bangor the upper member of the Martinsburg formation can be separated into two parts, which, following the quarrymen, may be called the Bangor beds (below) and the Pen Argyl beds (above). Although the exact thickness of the entire series of Bangor or of Pen Argyl beds is not determined with certainty because a complete section across either division is not afforded and because the crumpling of the beds is too severe, exact measurements were made of parts of these smaller stratigraphic divisions as exposed in quarries. In all cases the strata were measured in parts of an inch, the rule being laid along the cleavage; the values obtained were then recalculated to yield actual thicknesses as measured at right angles to the bedding planes.

Where the thicker beds can be identified and correlated, they serve as key horizons. In this way, generalized values of the thickness of slate intervening between two beds can be ascertained, whenever that thickness is exposed in the quarries. As already mentioned, the values for the beds intervening between big beds vary sharply with the structural position of the section measured. The table which follows is therefore generalized.

Within the Bangor and Pen Argyl beds there are local disagreements as to the names applied to some of the runs and to their subdivisions, the separate beds, but the most generally accepted terms have been used in the following table.

The figures given represent average thicknesses in feet. Parts of the sequence were measured in detail, others were only estimated.

Uses of beds in eastern part of Lehigh-Northampton district. The principal use of the "soft" slate, here as at Slatington, is for millstock and roofing slate. In the Pen Argyl beds, the slate below the Albion "run" and above the Pennsylvania "run" seems to be better suited for structural, electrical, and blackboard material than for roofing. The Gray bed of the Albion "run" makes exceptionally fine roofing slate. Beds light in color and hence low in carbon are used for electrical material. Certain thin, dark beds at Bangor, especially in the North Bangor, North Bangor No. 2, and North Bangor No. 3 "runs," are used for school slate, but the production of school slate in this part of the region is not large. Practically all of the big beds are used in making blackboards.

Correlation of eastern and western parts of Lehigh-Northampton district. It was hoped that detailed measurements would show a correspondence between the beds of the Bangor and Pen Argyl region in Northampton County and those of the Lehigh-Northampton district, as exposed from Danielsville, Northampton County, westward. Such

Table of soft slate beds; eastern part of Lehigh-Northampton district.

| | | Thickness
in feet |
|--------------------------------|---|----------------------|
| Pen Argyll
beds | Pennsylvania "run" { | |
| | Intervening beds | 21 |
| | Big bed | 12.5 |
| | Intervening beds | 110 |
| | Unmeasured thickness, including the United States "run" | |
| | Johnny Knack bed | 10 |
| | Intervening beds | 46.5 |
| | Genuine big bed | 6 |
| | Intervening beds | 5 |
| | Red bed | 9 |
| | Intervening beds | 56.5 |
| | Big bed | 7.5 |
| | Intervening beds | 255 |
| | Jemmy Weeks bed | 10.5 |
| | Intervening beds | 33.5 |
| | Hard big bed | 12 |
| | Intervening beds | 3 |
| | Big bed | 7.5 |
| | Intervening beds | 72.5 |
| | Gray bed | 5.5 |
| Bangor beds | Albion "run" { | |
| | Intervening beds | 14.5 |
| | Genuine big bed | 14 |
| | Intervening beds | 3 |
| | Hard Front big bed | 8 |
| | Intervening beds | 76 |
| | Acme "run" { | |
| | Big bed | 6 |
| | Intervening beds | 41.5 |
| | Big bed | 5.5 |
| Bangor beds | Intervening beds | 27.5 |
| | Big bed | 11.5 |
| | Intervening beds | 5.5 |
| | Big bed | 9 |
| | Intervening beds | 283 |
| | Phoenix "run" { | |
| | Big bed | 4.5 |
| | Intervening beds | 12 |
| | Big bed | 5.5 |
| | Intervening beds | 27.5 |
| | Big bed | 4 |
| | Unmeasured thickness, largely sandy | |
| | North Bangor No. 3 { | |
| | First big bed | 12 |
| | Intervening beds | 23 |
| | North Bangor No. 3 { | |
| | Second big bed | 11 |
| | Intervening beds | 49 |
| | North Bangor No. 2 { | |
| | Big bed | 6 |
| | Intervening beds | 50 |
| | North Bangor "run" { | |
| | North Bangor big bed | 7 |
| | Intervening beds | 60 |
| | Mike Taylor big bed | 8 |
| | Intervening beds | 141 |
| | Bangor Union "run" { | |
| | Bangor Union big bed | 8 |
| | Intervening beds | 75 |
| | Black Ribbon big bed | 5 |
| | Intervening beds | 36 |
| | Old Bangor "run" { | |
| | 13 big bed | 5 |
| | Intervening beds | 52 |
| | Gray bed | 7 |
| | Intervening beds | 22 |
| | Middle (Gray Bed) big bed | 7 |
| | Intervening beds | 25 |
| | 9-foot big bed | 3 |
| | Intervening beds | 25 |
| | Grand Central "run" { | |
| | Grand Central First big bed | 4 |
| | Intervening beds | 25 |
| | Grand Central Second big bed | 8 |
| Total thickness, minimum | | 1874.5 |

a correspondence could not be established with certainty, however. There exists, nevertheless, one basis for a possible correlation.

At Pen Argyl there is a peculiar olive-green, highly chloritic bed, the "Gray" bed in the Albion "run" of the Pen Argyl group. A layer of similar composition and appearance is exposed in the Hower, Banner, and Montgomery quarries of the Berlinsville region, and is said also to have been found at App's barn, three-fourths of a mile west of Berlinsville and $1\frac{1}{4}$ miles east of Walnutport. It is very likely that these several occurrences represent one and the same layer. This bed seems to be about as high above the uppermost prominent sandy layers of the middle Martinsburg as is the Gray bed of the Pen Argyl "run." It should be mentioned that a similar bed is found in the quarries of the Columbia group at Slatedale but seems, from structural considerations, to be about 400 feet higher in the sequence. Some of the older slate operators subscribe to this correlation and regard the beds beneath the "Gray" bed in the Danielsville region as equivalent to those beneath the "Gray" bed at Pen Argyl; thus, the Knifey bed of the Hower quarries at Danielsville is thought to be the equivalent of the Genuine big bed of the Albion "run" at Pen Argyl. In that case, the strata of the Pen Argyl group of eastern Northampton County would be the approximate equivalents of the beds of the Slatington region from the Franklin "run" upward, whereas the strata of the Bangor group of eastern Northampton County would correspond to the beds from the Franklin "run" downward. This correlation could not be established with absolute certainty on the basis of measurements, however, as the few good exposures of the critical region between Danielsville on the west and Wind Gap on the east are in quarries which are now inaccessible because abandoned.

For practical purposes, it has seemed wiser to separate the strata of soft slate exposed in the quarries of the Slatington group on the basis of certain prominent beds especially well recognized at Slatington, rather than to carry westward the units employed in mapping in the eastern part of the Lehigh-Northampton district, which are no longer clearly recognizable in the Slatington region.

THICKNESS OF STRATA

A striking difference between the Bangor-Pen Argyl and the Slatington regions is in the relative thickness of the beds. This is confirmed by comparing the thicker or "big" beds in these two regions, remembering that figures represent actual thicknesses measured at right angles to the bedding plane of the layers in question. The thickest bed of the Bangor-Pen Argyl region is the Genuine big bed of the Albion "run"; it averages $14\frac{1}{2}$ feet from top to bottom. As compared with this, the Upper Washington big bed at Slatington is 20 feet thick and reaches a maximum of 47 feet in one measurement.

To what extent thickness is related to folding and to what extent it expresses the relative quantity of sediment laid down during the deposition of the stratum cannot with certainty be determined. The beds at Bangor are certainly more closely compressed than anywhere at Slatington, as shown in the pinching at the trough of the Bangor syncline where exposed in the Bangor Union and Old Bangor quarries. Nevertheless differences in degree of compression cannot account entirely for the relative thinness of the beds at Bangor, for even in

the troughs and crests of the folds the strata do not attain thicknesses equal to those at Slatington, and at various points on the limbs of the open folds at Pen Argyl they are still decidedly thinner than at corresponding places on the equally open Slatington folds. It seems most probable, therefore, that the markedly greater thickness of beds at Slatington is due chiefly to the accumulation of more material than at Pen Argyl and Bangor, and that the beds thicken westward.

This exceptional thickness of individual beds in the Slatington district makes the removal of such conspicuously massive layers feasible; the rest of the slate is left in the hole, or quarried and abandoned as waste, or, most commonly in well-conducted operations, reduces the cost of quarrying by serving for structural slate. If it is profitable to follow individual beds, mining becomes feasible, and hence at Slatington several tunnels and at least one shaft are developed, whereas at Bangor and Pen Argyl open pits alone are used.

COLOR AND APPEARANCE

The "neutral gray k" of the modified Ridgway color chart,¹ published by the National Research Council, corresponds most nearly to the dominant color of the Lehigh-Northampton slates. The carbonaceous "ribbons" are almost black and the siliceous "ribbons" have a faintly metallic or silvery sheen, which, from a distance, gives the slate a somewhat lighter shade than the average but does not change the actual color.

"Soft" and "hard" slate do not materially differ in color. The width of the banding is narrower in the "hard" slate, so much so that no unbanded slate can be obtained; as the banding is slightly visible when the slate is used on the roof, a distinction is made by the user between the "soft" and "hard" roofing slate.

In the "soft" slate there are olive-green layers,—one at Pen Argyl (in the Albion "run") and one at Bangor (in the Old Bangor "run"); there are also beds of similar color at Slatington, which may be the equivalent of one or both the Bangor-Pen Argyl greenish beds. These strata are spoken of as "Gray" beds, the name being due to their light gray color, in contrast with the dominant blue-gray or "blue" of the district. On the modified Ridgway color chart, the color of the Gray beds is essentially "25^d."

The red, green, and yellow shales that are quarried at Albany, Greenawald, and Lenhartsville vary greatly in color. A common red is a brick, jasper, or catlinite color, lying between "1^{3a}" and "1^{3o}" on the one hand and "7^{2o}" on the other; another is near "1³⁺¹". The greens are "olive-green," near 35^{5o} and "35^{5d}." Occasional beds in this part of the sequence, even when fresh, have a color lying between "salmon" and "yellow ocher,"—about "17^{2d}" or "21^{2b}."

A faint rusting after the lapse of several years and a slight paling are the only noteworthy changes of the typical slate, whether "hard" or "soft" in the Lehigh-Northampton district. The Gray beds show no appreciable change.

THE PROBABLE POST-MARTINSBURG UNCONFORMITY

It has already been pointed out (pages 149, 172) that, either through post-Martinsburg, pre-Tuscarora erosion, or through lack of sedimen-

¹ Goldman, M. I., and Merwin, H. E., Color chart for the description of sedimentary rocks: National Research Council, Division of Geology and Geography, 1928.

tation in late Martinsburg time, the upper member of the Martinsburg formation is absent from Eckville in the Hamburg quadrangle westward. The conclusion seems justified that this absence of the uppermost slate member is attributable to a post-Martinsburg erosion interval; but whether it be accepted or not, the significance of the observed fact is that all slate quarrying in the most promising part of the Martinsburg, namely the uppermost member, is definitely excluded west of Eckville.

EFFECT OF STRUCTURAL FEATURES

Effect of major structural features, western part of district. There are five conspicuous structural features that effect the development of the slate in the western part of Northampton and in Lehigh and Berks counties. They are the Eckville, Mosserville and Snyderville folds and the Eckville and Schuylkill Gap faults. These structures have already been described on pages 159-160 and 162-164.

The series of pitching synclines and anticlines in the neighborhood of Eckville have little significance in the development of the "soft" (or uppermost Martinsburg) slate. Because of the unconformity between the Martinsburg and the overlying Tuscarora, which reduces the thickness of the upper Martinsburg southward and westward, the effect of the folding is to carry the "soft" slate outcrops higher up the slope of Blue Mountain from Eckville (Hamburg quadrangle) westward, and simultaneously to narrow the outcrop. Under these conditions, talus from the Tuscarora completely covers what little of the "soft" slate might otherwise outcrop. Hence, through a combination of these various unfavorable factors, the "soft" slate cannot feasibly be quarried south and west of Eckville.

The westward pitching anticline at Mosserville (Hamburg quadrangle) and the several minor drag folds on the south side of the corresponding syncline half a mile south of that little town, merely complicate the outcrop of the "soft" slate by repeating the appearance of the upper member of the Martinsburg formation on both sides of the middle Martinsburg anticline. This repetition accounts for the slate quarries south of Mosserville, the band of sandy rock (middle Martinsburg) north of that town, and the reappearance of workable "soft" slate in an old quarry about one mile north of Mosserville. The westward pitch of the Mosserville anticline carries the sandy member underground a mile north of Lynnport, so that "soft" slate quarries, now abandoned, have been opened from Lynnport northwestward almost all the way to Blue Mountain.

The Snyder'sville syncline in the Slatington quadrangle has already been described. Its economic importance consists in the fact that it preserves a downfolded remnant of "hard" slate of the lower Martinsburg in an area otherwise underlain solely by pre-Martinsburg limestone. This fact made possible the operation of the long abandoned "hard" slate quarry a quarter of a mile southeast of Stetlersville. Followed southwestward the contact between the lowest Martinsburg and the subjacent limestones gives evidence of several similar synclinal areas of Martinsburg "hard" slate, but so far as known none of these structures has actually been worked for slate.

The Eckville fault has the effect of widening the outcrop of the upper part of the middle, sandy Martinsburg. Its economic significance is negligible.

The ("Schuylkill Gap") fault which shows immediately south of Schuylkill Gap, Pottsville quadrangle, brings sandy middle Martinsburg against Tuscarora quartzite. It therefore helps cut out the upper, "soft" slate member of the Martinsburg. Its most important economic effect is to offset (in a way not yet fully understood in three dimensions) some of the layers of colored shale or "slate" that are quarried for pigment in the neighborhood of Greenawald and Albany. The lesser faulting shown along the east side of Blue Mountain between this fault and the Eckville fault produces similar but even less noteworthy effects. Economically considered, therefore, these several faults are not of great importance.

Effect of major structural features, eastern part of district. From Slatefield eastward the larger structure is a moderately regular monocline dipping northward. There are no great departures from this general structure of the "soft" slate until at East Bangor the strike turns sharply so as to trend due northwest at the Consolidated No. 2 quarry. This is probably a part of the same general fold that yields a pitching syncline in Silurian rocks at the Big Offset. It has the effect of shifting the workable beds associated with the Gray bed at Bangor farther north than would be expected from the strike of the strata at Bangor.

At Portland on Delaware River an anticline bounded by two faults that are probably separate, brings older limestone to the surface between two belts of "hard" slate. Westward these faults have no economic significance, but near Delaware River they are instrumental in repeating the "hard" slate, so that it can be quarried in the hills $1\frac{1}{2}$ miles north of Portland, as well as south of Portland at Mount Bethel.

Details of structure have affected quarrying considerably in various localities. Minor faults striking generally at right angles to the strike of the beds have already been described (see page 164). They displace the beds in unexpected fashion and have contributed materially to the difficulties of quarrying, notably at Pen Argyl. The very flat Bangor syncline opened in the North Bangor, Bangor Union, and Old Bangor quarries has made it possible after passing through a bed, to quarry the same stratum at greater depth; this is perhaps the most striking structural feature exposed in the quarries of the Lehigh-Northampton district.

On the whole, there are fewer large structural features that complicate quarry development in the eastern than in the western part of the Lehigh-Northampton district.

Cleavage. Attention has already been directed to the change in dip of cleavage from gentle angles in the eastern part of the district to steep ones in the western part (see page 170).

The effect of this change is seriously to influence the mode of working the quarries. At Pen Argyl and Bangor quarrying is carried downward in a series of steps, a "key block" being taken out and the "feathers" or wedges being put in from the sides after the key block has been removed. Blocks are thus lifted vertically from the quarry bottom, which is essentially horizontal. At Slatington, on the other hand, the "feathers" must be driven at angles of 50° - 60° to the horizontal, and difficulty is experienced in providing a relatively flat surface on which the workmen can stand. A comparison is given in the

technical studies by Bowles.¹ Further, the steep dip of the cleavage at Slatington favors the use of the broadening bar in quarrying, as against the wire saw or channeller, which are preferred at Pen Argyl and Bangor² (see also page 30).

In a few places the cleavage shows gentle curvature so that a block of quarried slate is not absolutely flat. This does not interfere with the use of the slate for most purposes, however, as the curve is generally so slight as not to be noticeable in short lengths; it is only deleterious in the manufacture of blackboards and then only rarely.

Jointing. What has already been said as to the relations between joints and successful quarrying (see page 45) applies no less in the Lehigh-Northampton district than elsewhere. In addition the marked banding in the slate of this region—especially in the “soft” slate, where such banding in quarried blocks is to be avoided as much as possible in making roofing slate, blackboards, and switchboards—makes the angular relations between bedding strike and jointing of great importance (see page 49).

Both in the eastern and western parts of the district the joints are roughly parallel to the strike of the beds (see Plate 12, B, B¹, C, C¹). In detail there are marked exceptions in some quarries, however. In two cases lesser pitching synclines, with axes inclined to the regional strike, are correlated with radiating joint systems that are ruinous to quarry operations (see Figure 17, page 44).

False Cleavage. Places where this feature was especially noted are in the quarries at Danielsville, Bassards Corners, Berlinsville, and Apps (Mauch Chunk quadrangle); at some of the quarries near the National School Slate Company's factory in Slatington and north and northwest of that town; at several of the quarries near Little Run Junction and Custer (Slatington quadrangle). In all of these places, however, the false cleavage appears to be limited to certain beds and is not prohibitive of quarrying as a whole.

DETAILED QUARRY DESCRIPTIONS

PLAN OF PRESENTATION

The slate deposits of the Lehigh-Northampton district are spread over so wide an area that it has not been practical, even on the base maps used, which have a scale of 1:62500, to combine all of the quarries on one sheet. For convenience, therefore, both in the mere matter of handling the map and also because the geology of the two halves differs somewhat, the Lehigh-Northampton district is here subdivided into two parts—an eastern and a western, the line between the two being along the meridian of 75°30'00" west longitude. The eastern part thus lies in the Delaware Watergap, Wind Gap, and Allentown quadrangles and wholly in Northampton County. The western part lies in the Mauch Chunk, Slatington and Hamburg quadrangles and comprises parts of Northampton, Lehigh, and Berks counties. Certain general differences, especially in the details of the stratigraphy, be-

¹ Bowles, Oliver, The technology of slate: U. S. Bur. Mines, Bull. 218, pp. 45 and 46, 1922.

² Foelt, Doster (Discussion) and Behre, C. H., Jr., Geologic factors in the development of the eastern Pennsylvania slate belt: Am. Inst. Min. Met. Eng. Trans., vol. 76, pp. 406, 410-412, 1923.

tween these two divisions have been discussed under "General Geology" (see pages 157-160, 170) and "Economic Geology" (especially pages 186-190, 194-195).

Two small-scale maps (scale 1:62500) have been prepared, to correspond to the two divisions mentioned. On these maps the quarry regions fall somewhat naturally into smaller divisions separated by areas without quarries. These smaller divisions or "groups" have been arbitrarily designated with names from a town or village centrally located with respect to the quarry group. Since the products of "hard" and "soft" slates differ appreciably, the groups are so arranged that no single one includes both "hard" and "soft" slate quarries.

For ease in finding, the quarries in each group are numbered consecutively, the numbers generally running from west to east. Corresponding numbers are entered on the small-scale maps and also in the text at the head of each quarry description. To facilitate finding on the maps or in the field, the quarry names most commonly applied to them are used throughout the text, and are also entered, with the corresponding numbers, on the backs of the small-scale maps. In a few cases alternate names are also given in parentheses. In many instances no name could be found and for such quarries the number alone is used.

Special large-scale geologic maps of the Pen Argyl-Bangor and Slatington regions are also introduced to show details for which the smaller scale maps are inadequate. On these the quarries are not named or numbered, but they can be identified by comparison with the larger maps.

The plan followed is to describe in a general fashion the geologic conditions prevailing in the region of a given quarry group. This is followed by a description of each opening, which includes a brief statement as to location, a mention of the approximate size of the quarry, an account of the structure, the beds worked, and any special geologic features having an economic bearing, and finally a very brief statement as to the quarry history and type of products obtained.

QUARRIES IN EASTERN PART OF DISTRICT¹

SLATEFORD GROUP.

The quarries of this group are all within a mile of Slateford and would, when operating, obtain their supplies and ship their products from Slateford. They are openings wholly in the soft belt, that is, the slate is soft to the chisel, has well developed cleavage, and is distinguished by the greater distance which separates the "ribbons," or, to put it another way, by the width of the individual beds.

The sequence of the subdivisions of the Martinsburg, in this group, is, in the order of superposition, the oldest beds below:

- Pen Argyl beds
- Bangor beds
- Middle, sandy member
- Lower, hard slate member

The northern edge of the middle, sandstone member of the Martinsburg formation appears in the bottom of Slateford Creek, east of Wil-

¹The descriptions of these quarries are from Bulletin M-9, the only noteworthy changes being due to recent developments.

Williams quarry and on the hillside to the south, a few hundred feet east of the Frye quarry. It is clear, therefore, that the Frye quarry is in the Grand Central "run," and it is highly probable that the Williams and Snowdon quarries are higher in the Bangor beds. Quarry Number 1 in this group and the Washington Brown quarry are more probably in the Pen Argyl beds, as it would seem that a considerable thickness of slate lies between these and the holes first mentioned; further, where the old road from the Snowdon quarry crosses the west branch of Slateford Creek three-tenths of a mile west of Williams quarry, heavy sandy beds show in the creek bottom, strongly suggesting the sandy layers at the top of the Bangor beds.

In the quarries of this group, the dip of the beds is generally gentle; the cleavage has a fairly uniform strike, which is generally northeast, but in places in the northern openings the cleavage planes dip north. The grain is uniformly northwesterly in trend. Jointing was not studied with care here. Faulting is conspicuous, having been described in both the Snowdon and Williams quarries.

The products included roofing slate, blackboards, electrical slate, and sanitary and structural materials. All of the quarries here are abandoned.

1. This is a small opening showing 20 feet of slate above the water level. The beds strike $N.45^{\circ}E.$ and dip from 22° to $37^{\circ}N.$, flattening northward. The cleavage strikes $N.45^{\circ}E.$ and dips $10-25^{\circ}N.$, also flattening northward. The beds are from two to six inches thick. A few fractures were observed dipping two or three degrees more steeply than the cleavage and in the same direction. The quarry has long been abandoned and is now full of water.

2. *Washington Brown Quarry.* This is an old quarry 50 by 125 feet in plan and probably 100 feet deep. The beds strike $N.42^{\circ}E.$, dipping $21^{\circ}NW.$ The slate appears to be of fair quality, not heavily ribboned, but there are some sandy beds. The material on the dump shows considerable rusting, but an absence of heavy jointing and little indication of quartz or calcite stringers. The cleavage strikes $N.25^{\circ}W.$ and dips $18^{\circ}SW.$ This is probably the quarry said by Sanders¹ to have just been opened in 1874.

3. *Williams Quarry.* This quarry is in the valley of Slateford Creek about half a mile from its mouth. It is an amphitheater 150 feet square and 40 feet deep, whose sides are formed by the valley walls.

At the south end of the cut the bedding strikes $N.50^{\circ}E.$, dips $20^{\circ}NW.$; in the north end it strikes $N.50^{\circ}W.$ and dips $20^{\circ}SW.$ The cleavage has a strike of $N.60^{\circ}E.$, and dips $20-25^{\circ}S.$ It appears, therefore, that both ends of the cut are on the under limb of a fold the axial plane of which dips gently southward; at the southern end of the opening the dip is north, as this hypothesis would require, while at the northern end, preparing for a rise over the axial plane of the complementary fold below, a southward dip appears.

A set of small, rather inconspicuous, calcite-filled joints strikes $N.70^{\circ}E.$ and dips $36^{\circ}SE.$, just under a calcite-filled fault, which appears on the south wall of the quarry near the creek level, striking $N.20^{\circ}E.$ and dipping $16^{\circ}NW.$

¹ Sanders, R. H., *Geology of Lehigh and Northampton Counties: Pa.* Second Geol. Survey, D3, vol. 1, p. 86, 1883.

4. *Snowdon Quarry.* This quarry is 350 by 200 feet and shows 30 feet of slate above water level.

At the southeastern edge, the beds appear to dip gently toward the south, probably not over 15° ; at the northwestern side they seem to steepen so as to dip as much as 60° , but as the sides were not accessible and the bedding indistinct these observations are poor. They fit, however, with the conception developed for Williams quarry (see above), for the beds here would then be the upper limb of a fold complementary to and above that whose lower limb is seen in Williams quarry. The strike of the bedding is parallel to that of the cleavage. The cleavage is very uniformly $N.45^{\circ}E$ and dips $28^{\circ}SW$. The slate, though rather heavily ribboned, is soft and apparently easily sawed. It bears some calcite and quartz on its joint faces and a little pyrite occurs with the calcite. Small-scale faulting was observed in some of the blocks on the dump. (See Figure 57.)

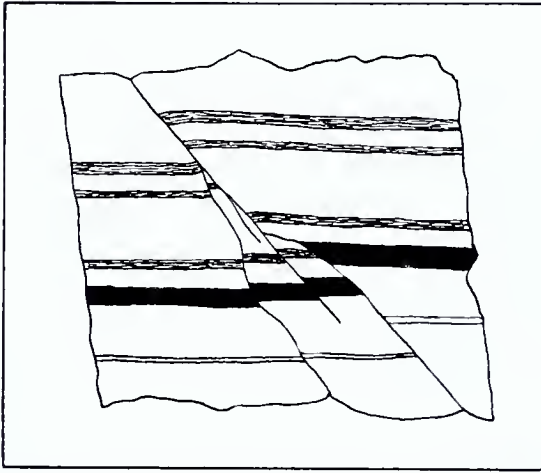


Fig. 57. Sketch of small fault; entire fault trace is 16 inches long. From dump of Snowdon quarry.

This quarry is said to have been opened in 1870. Operations were discontinued about 1920. The quarry property still bears a mill, with remnants of equipment.

5. *Frye Quarry.* This opening is an elongated cut 210 by 85 feet in size and 20 feet deep. The beds, generally indistinct, appear to strike $N.32^{\circ}E$. and are virtually horizontal. The cleavage has a strike like that of the beds, but dips $35^{\circ}SE$. The opening is in about the same position structurally as the Snowdon quarry beds, i. e., on the upper limb of an antiline so far overturned to the north as to give it a nearly flat axial plane dipping gently south.

This quarry was worked before about 1875 and Sanders¹ found it abandoned.

BANGOR GROUP.

The Bangor group quarries are mostly close to the town of Bangor. All of them secure the major part of their supplies from Bangor; it is their shipping point, and the men employed are mainly residents of Bangor and East Bangor. The New York quarry, which is the farthest

¹ Sanders, R. H., op. cit., p. 89.

out, lies about three miles by road from the city. Most of the openings are on either side of the State highway connecting Bangor and East Bangor.

The quarries of the Bangor group are, like those at Slateford, in the soft belt. The sequence of the minor divisions of the Martinsburg formation has been presented on a preceding page (p. 191). The big beds mentioned in that description may be identified in the quarries of the Bangor group and were first named in them. At Johnsonville, $4\frac{1}{2}$ miles northeast of Bangor (see Plate 24), there is a narrow strip of the hard slate, followed to the north by a section almost a mile wide underlain by the middle, sandy member of the Martinsburg formation. North of the sandy member is soft slate, succeeded by a belt of rock more sandy than the normal soft slates. This sandy belt marks the northern limit of the Bangor beds. It is traced westward toward Bangor with difficulty, so that the northern edge of the Bangor beds is not generally identifiable in the field and a doubt consequently exists as to the location of the line between the Bangor and Pen Argyl beds. South of and stratigraphically lower than the sandy slate near the top of the Bangor beds, however, are almost all the quarries of the Bangor group. The exceptions are the New York, Hoboken, and Northampton quarries, which appear to be too far north of the lower part of the Bangor beds to be included in that member of the Martinsburg formation. Although absolute correlation is lacking for these three quarries, it appears probable that they occupy a stratigraphic position somewhere immediately above or below the Albion "run" in the Pen Argyl beds.

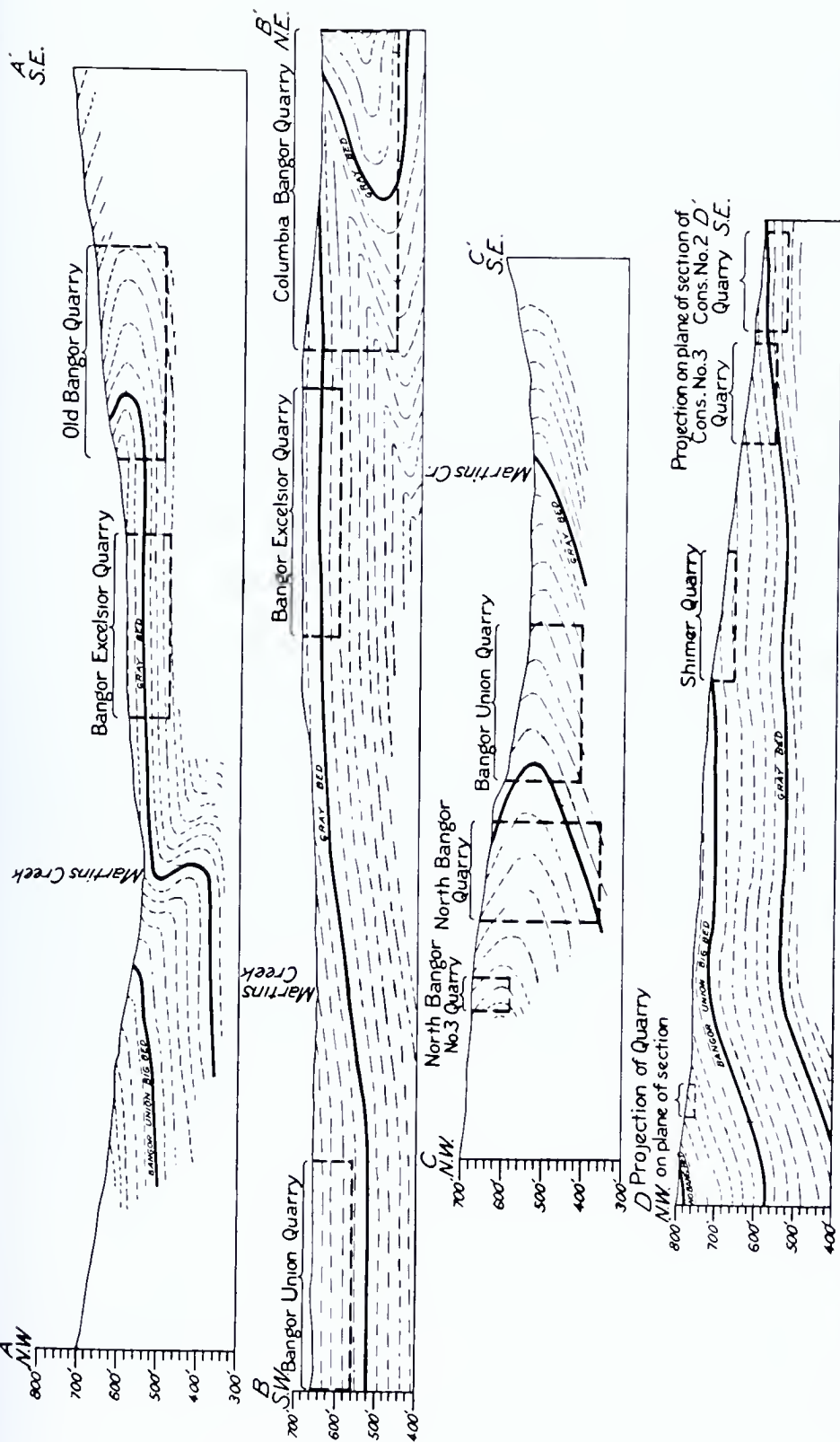
The quarries of the Bangor group lie on folds of which the limbs are generally closely opposed and the axial planes almost horizontal. Consequently it is not rarely the case that an opening, beginning at the surface in beds dipping southward at low angles will, as greater depth is acquired, traverse the same beds but in the inverse order and dipping north. The change in the angle of dip will thus rapidly alter the width of outcrop of the beds. To this may be added, as another factor in the production of irregularity in width of outcrop, the topographic effect; for the relief, or difference in altitude between the hills and valleys, is far greater at Bangor than elsewhere in the immediate region and its effect in shifting the outcrop of the Bangor beds, dipping at gentle angles, is marked. These features combine to necessitate the greatest caution in foretelling what beds will be met with in a new quarry opened in the Bangor region.

The Bangor group of quarries exposes several folds. One of these is the Old Bangor syncline. Both limbs of this structure appear in the Old Bangor, Bangor Union, North Bangor, and North Bangor No. 3 quarries. The lower limb alone appears in the other quarries at Bangor and East Bangor. The Columbia Bangor quarry shows, in addition a small syncline immediately below this lower limb, developed apparently as a drag fold, so that the lower limb of the Old Bangor syncline, as seen in the New Bangor quarry, is virtually continuous with that in the Bangor Central opening.

Another small syncline, but in this case with the limbs especially closely opposed, is to be seen in the New Peerless (Bangor Vein) quarry.

These folds appear to be parts of a large structure, a syncline whose axis lies well north of the town of Bangor. The syncline thus defined

PLATE 44.



Structure sections in region of Bangor; scale 1 inch=500 feet. *AA'* Section $N.55^{\circ}E.$ along northeast edge of Old Bangor quarry; *BB'* Section $N.37^{\circ}E.$ through Bangor Union and Columbia Bangor quarries; *CC'* Section $N.30^{\circ}W.$ through North Bangor No. 3 quarry; *DD'* Section $N.35^{\circ}W.$ through Shimer quarry.

has a westward pitch, the axis emerging at the Shimer, Consolidated No. 3, and Mountain View quarries. This fold may, in turn, be only a larger drag fold on a still larger synclinal unit, but evidence for such an interpretation is lacking as the beds are covered northward by younger formations.

Very probably the beds in the Hoboken and New York quarries are similarly parts of a syncline, the axis of which is emerging, as the strikes are almost due north and the dips gentle and westward.

The dip of the beds in the quarries of the Bangor group is gentle and the structures either strike northeast (more commonly) or northward (if the opening lies close to an emerging axis). The cleavage planes generally strike northeast, roughly paralleling the bedding planes, but where axes emerge the strikes of cleavage and bedding intersect. The grain is uniformly northwesterly in trend.

Jointing was studied in detail in this group of quarries. In a few quarries the joints radiate so as to fall in all points of the compass and generalizations in these instances become impossible; such quarries are always located on the ends of pitching troughs or on minor folds whose axes lie transverse to the strikes of the larger structural features. In most other cases generalizations in regard to joint strikes are difficult to frame. Two types of joint patterns may be recognized. In one the strikes of the greater number of joints form small angles on either side of the bedding strike; since the beds generally strike northeast, the joint strikes form obtuse angles toward the southeast; this pattern is well illustrated in the Columbia Bangor, New Bangor, and North Bangor quarries. The second type is exemplified by the Bangor Union and Northampton quarries. In these cases, the intersections of the joints form acute angles toward the southeast. Intermediate are such patterns as those of the Bangor Central and North Bangor No. 3 quarries. In general it seems that the strikes of joints nearly parallel the bedding strike or are almost if not quite at right angles to it. This general correlation suggests that the joints owe their origin to the same thrusts to which the folds are attributable. However, the occasional turning of cleavage at joints, their calcite or quartz filling, and the relations of some joint systems to bedding-slip faults that are clearly later than the folding of the slate,—these and other considerations compel recognition of the fact that jointing is generally of later date than the folding of the slate. The apparent relation between the joint patterns and the folding is perhaps best explained by the similarity in the direction of the two separate thrusts which produced the folds at one time and the joints later.

The products of the quarries of the Bangor group are varied. They include roofing slate, structural slate, blackboards, electrical slate, slate for "marbleizing", school slate, and crushed and pulverized slate. The outstanding product of the quarries of the Bangor group is roofing slate. Structural slate is of some importance, and electrical slate and blackboards less so, but most of the trade of all quarries excepting the New York and Northampton is in roofing slate.

In 1927 the number of operating quarries was twelve. This district vies with that surrounding the town of Pen Argyl for position as the leading slate region in Northampton County.

1. *New York Quarry.* This quarry is three-tenths of a mile north-

west of North Bangor station on the Lehigh & New England Railroad. It is a moderate-sized opening 190 feet deep.

Here the beds dip northwest, 30° at the south end, 22° toward the north. A remarkable feature is the unusual strike of the beds, which bears almost due north. This feature corresponds to a more northerly strike also at the Hoboken quarry. Taken by and large this suggests that the New York quarry is opened along the axis of a westward plunging fold. If the Bangor Vein quarry is in beds of the North Bangor No. 3 "run", it seems quite probable that the beds of the New York quarry are somewhere above the Albion "run" of the Pen Argyl beds. However, confirmation is lacking.

On the working level the cleavage strikes generally $N.60-70^{\circ} E.$, and dips $23-24^{\circ} S.$ The grain strikes $N.48^{\circ} W.$ The quarry has one very regular system of joints which strike $N.20-35^{\circ} E.$ and dip from 60° to $90^{\circ} N.$ Small joints, apparently associated with slippage (see below) are seen in the east corner and strike generally due east, with southward dip. A single very prominent $N.36^{\circ} E.$ joint carries on from the working level all the way to the surface, dipping $45^{\circ} S.$

Near the middle of the quarry two calcareous beds, about 4 feet apart in actual thickness, show heavy mullioning on the face of each; the strike trends $N.40^{\circ} W.$ The heavy "rolls" developed by the movement have their steeper sides toward the north; hence it is clear that the top beds have moved up, the lower beds down, along this bedding plane, which has served as a plane of movement. The lower calcareous bed is cut by the southwest quarry wall, and clearly shows slice-like fracturing; each section or slice has, at its south end, been pushed up over its neighboring slice to the south. Nevertheless, the slate beds immediately above and below show no distortion except for a slight steepening in the angle at which the cleavage intersects them. This suggests that there has been relatively little movement since the cleavage was formed. However, just above the upper calcareous bed are stringers of quartz and calcite dipping obliquely southwest; these show that some movement has taken place either during or subsequent to the development of cleavage, a movement not taken up in the growth of the sericite flakes and therefore occurring not earlier than the later stages of sericitization; the fact that most of the joints stop at one or the other of the calcareous beds mentioned, supports the same conclusion. In short, it is evident that there have been two periods of movement, one in which the calcareous beds were folded and fractured and the clayey material (which today is slate) simply flowed around them; the second in which the clayey material, having been converted into brittle mica, was pulled apart by later stresses and developed joints and quartz-calcite-filled fractures.

These two calcareous beds are good examples of the "loose ribbons" so often met with in the soft belt quarries.

Only one big bed, which is about 6 feet long along the cleavage was seen; this has at the south a "hard roll" which measures 18 inches along the cleavage.

It is thought that the movement along the calcareous beds mentioned above served to relieve the strain, and that jointing should be relatively negligible below the lower of the two beds. This should enhance the value of the quarry.

This quarry was opened about 1885 by Solomon Flory. Operations were stopped in 1909 but in 1911 the property was purchased by Thos. Bolger of Bangor and subsequently reopened.

A well furnished mill is operating on the property. All types of slate products have been made here in the past, but in 1927 the yield was chiefly millstock.

2. *Hoboken Quarry.* The Hoboken quarry is about two miles north of Bangor, within 900 feet of the Lehigh & New England Railroad. The opening measures about 125 feet square.

The slate has an overburden of six feet of glacial boulders and rounded gravel. In the northeast corner the beds strike N.25°E. and dip 17°NW.; in the southeast corner the strike swings more easterly, being here N.35°E., with a dip of 20°NW. Thus the beds are on the under limb of a syncline overturned to the north. In what part of the Pen Argyl beds they lie is uncertain; it seems probable that they are slightly higher than the strata quarried at the New York quarry. One large bed shows on the east side of the quarry, about 3½ feet thick. The cleavage strikes generally N.65°E. and dips 40°SE. Grain trends N.45°W. and is constantly vertical. Only one conspicuous joint was seen; this strikes N.10°W., and dips 70°NE.

This pit has evidently not been operated in recent years. A long-unused mill, apparently once fairly well equipped with planers, saws, and one rubbing bed, stands south of the quarry.

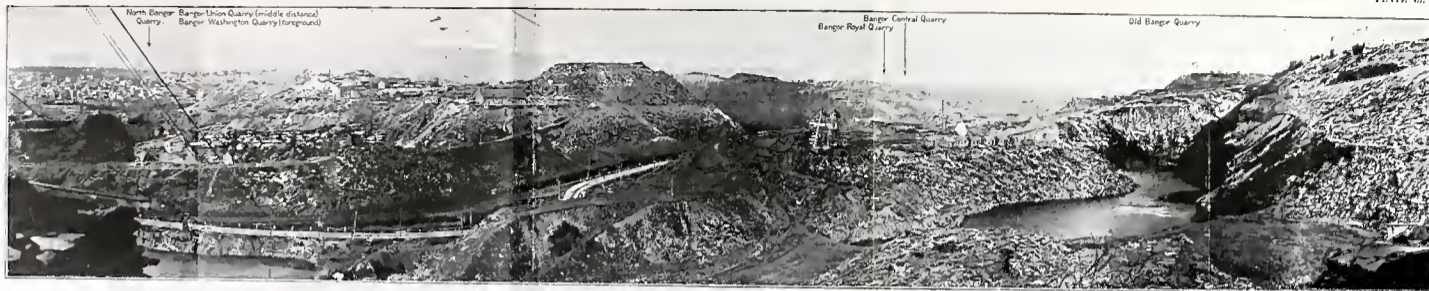
3. *Strunk Quarry.* This and the New Peerless quarry are on opposite sides of the road leading to the mill of the New Peerless (Bangor Vein) quarry. They are about 150 feet apart and 1.3 miles due north from East Bangor.

The Strunk or Peerless quarry is about 200 feet square and about 80 feet deep.

In the southeast wall the beds are tightly folded and show minor crumplings along and parallel to the axis of a syncline overturned toward the north, whose axial plane strikes N.85°E. and dips about 13°S.; this axis pitches westward and shows again in the New Peerless quarry.

The thickening and thinning of beds is well shown in this fold, as is also the effect of the emergence of an axis on the direction of dip of beds; thus at the surface in the west corner, the beds are vertical, but only 15 feet below the surface they are horizontal; in the south corner, on the other hand, the strata dip 15° or less to the south on the upper limb of the fold; in the east corner the dip is opposite or 20°N. One big bed about 20 feet below the surface is to be seen in the middle of the southeastern wall. The same beds are exposed here as in the Peerless quarry. The cleavage strikes about due east and dips 15°S. The grain appears to trend N.15°W. and is vertical. One prominent joint, striking N.48°E. and dipping steeply south, was observed. Similar jointing is to be seen in the New Peerless quarry. This opening was probably first worked in 1890, but the quarry has not been operated for a long time, presumably not since 1900.

4. *New Peerless (Bangor Vein) Quarry.* The opening is about 460 feet by 225 feet. The beds exposed are thrown into a synclinal fold, having a northward overturn and an axial plane dipping here not more than 8° to the south, and striking about N.80°E. This axial plane,



A. Panorama of quarries at Bangor from Old Bangor Hill (Photograph by Bliss, Boston, Pa.)



B. Panorama east from dump of Parsons quarry, Pen Argyl (Photograph by Bliss, Boston, Pa.)

which is the same as that described in the Strunk quarry, seems to pitch 6° toward the west, as the synclinal axis appears only about 15 feet below the surface in the south corner of the Strunk, 60 feet below the surface on the northeast wall of the New Peerless and 100 feet below the surface on its west wall.

The beds record this structure quite clearly. In the upper level, about 60 feet below the surface, they strike $N.45^{\circ}E.$ and dip a maximum of $25^{\circ}S.$; in the lower level they strike similarly and dip a maximum of $60^{\circ}N.$

The beds in which this quarry is opened are probably the same as those of the North Bangor No. 3 quarry popularly known as the North Bangor No. 3 "run". In the classification here employed they lie a short distance up in the upper portion of the Bangor beds. This is the correlation generally accepted by slate operators, and as it appears to fit in well with the structure as worked out in these studies, it is here accepted.

Two very thick beds are worked in the lower level; both have a "length" along the cleavage of 16 feet, including the hard south end; their actual thicknesses are 15 feet in the case of the upper (more northerly) one and 16 feet, 8 inches for the lower bed. It is the upper big bed that is thought to be the equivalent of the North Bangor No. 3 First Big bed. The mean cleavage strike is $N.20-47^{\circ}W.$, and the dip is $13^{\circ}SW.$, but cleavage strike and dip are widely variable probably because of the disturbance caused by the bedding-slip fault mentioned below. The grain trends $N.40-47^{\circ}W.$ and is vertical.

Jointing falls into two systems. One of these has an average strike of about $N.30^{\circ}W.$, with 45° dips to the north; the second has steep dips, within a few degrees of vertical in either direction, and strikes $N.55^{\circ}W.$

The most striking structural feature in the quarry is a bedding slip fault. In the tight fold already mentioned as showing on the northeast side, the more southerly beds have been far more closely folded than those to the north. In the intense shear between these two sets of beds, a portion of the more southerly beds has been completely sheared off. The fault zone has been shattered and is largely filled with quartz; a series of small joints, striking $N.60^{\circ}E.$ and dipping vertically appears immediately above the fault zone; along it, also, the cleavage is very highly flexed. The fault disappears westward, where the folding of the southerly beds is not so sharp. From this it would seem that working westward in the quarry would carry the operators out of this undesirable shear zone and into less closely crumpled beds, having a uniform southerly dip.

This quarry is on the Peerless property. It was first worked in 1892, and was in operation in 1927. An interesting feature is the use of drilling and broaching in quarrying.

5. *Little Bangor Quarry.* The opening is 500 feet south of the Old Peerless quarry. The quarry is 45 feet square, its sides trending northeast and northwest, and about 40 feet deep.

The quarry should be in beds of the upper part of the Bangor Union "run", or in the lower part of the upper section of the Bangor beds. The beds and cleavage are about parallel, dipping gently southward. Grain trends $N.35^{\circ}W.$ and is vertical. Two sets of joints are recognized, striking respectively $N.20^{\circ}E.$, with dips of $80^{\circ}NW.$, and $N.55^{\circ}E.$, with



A. North half of northeast wall, New Peerless (Baugor Vein) quarry, showing relatively open fold of beds north of bedding slip fault. Compare with B.



B. South half of northeast wall, New Peerless quarry, showing close fold of beds south of bedding slip fault; the fault zone itself is highly shattered at A, but a closely folded bed shows south of it.

dips of 65° NW. These correspond to two similar systems in the New Peerless quarry. Some of the slate on the dump is distinctly "knotty."

This hole was opened about 25 years ago but has not been worked for the last twenty years.

6. This is a small cut about 30 feet square and 20 feet deep. Near the southeastern end one large bed, about $2\frac{1}{2}$ feet thick, strikes $N.35^{\circ}$ E. and dips 20° N. There are also several sandy, somewhat calcareous layers. The cleavage is near horizontal. The grain apparently trends $N.40^{\circ}$ W.

The flat cleavage in this quarry suggests the presence of another close fold toward the north.

7. *Mountain View Quarry.* This quarry is situated about 4,000 feet due north of East Bangor. It measures approximately 125 feet square, and is about 75 feet deep.

The strike of the bedding is $N.35^{\circ}$ W., with a dip of 9° toward the southwest. As the next outcrops to the north of this quarry show strikes that are again northeast and more nearly normal, it would appear that this opening is near the axis of a westward pitching syncline. The cleavage strikes $N.75^{\circ}$ E., dipping 20° S.; the grain trends $N.45^{\circ}$ W.

A single large bed about 2 feet thick with a "hard roll" a foot in thickness, outcrops 10 feet east of the southwest edge of the quarry. The beds worked here were probably those immediately above and below the Gray bed of the Old Bangor "run", although those exposed at the surface are all slightly higher.

A series of joints with $N.45^{\circ}$ W. strikes, dipping 55° NE., is prominent; there are also several vertical joints striking $N.20-60^{\circ}$ E.; on the southwest side are several vertical joints averaging $N.60^{\circ}$ E. in strike. The radiating pattern of these joints, so characteristic of openings on the ends of axes, is here well shown.

The products included milled material and roofing slates.

8. *Consolidated No. 3 Quarry.* Approximately 2,000 feet northwest of the town of East Bangor, in the direction of the ridge road, is an irregular opening, roughly rhomboid in shape, measuring approximately 350 feet on the side and about 100 feet deep.

In detail the strike of the beds in this quarry is variable, extending from $N.8^{\circ}$ to 25° W., with dips of 5° to 8° W. The major structure, like that in the Mountain View quarry, is a pitching syncline with a somewhat flat bottom, and it would seem that this quarry is nearer the axis, which has a 25° pitch westward. The Gray bed lies 50 feet below the surface along the northwest wall of the quarry. This shows that the opening is in the upper of the two sections of the Bangor beds. In the northwest wall of the quarry is the Black Ribbon big bed; about 18 feet below the surface of the ground and on the floor of the upper piece is the Thirteen big bed, which here has a thickness of 3 feet and a "length" along the cleavage of 8 feet.

The cleavage in general strikes $N.85^{\circ}$ E. and dips 24° S.; grain trends about $N.57^{\circ}$ W., which is unusual.

The jointing in this quarry is significant. The systems are numerous and the general pattern is radial. The following is a list of the joint strikes and dips actually observed:

Joints in Consolidated No. 3 Quarry.

| Strike | | | Dip | | Number | Strike | | | Dip | | Number |
|--------|-----|----|----------|--|--------|--------|-----|----|----------|----|--------|
| N. | 15° | E. | Vertical | | 3 | Due E. | | | 35° | S. | 3 |
| N. | 30° | E. | Vertical | | 1 | N. | 60° | W. | 70° | S. | 3 |
| N. | 46° | E. | 86° N. | | 1 | N. | 50° | W. | Vertical | | 2 |
| N. | 50° | E. | Vertical | | 1 | N. | 22° | W. | Vertical | | 1 |
| N. | 65° | E. | Vertical | | 1 | N. | 22° | W. | 80° | N. | 2 |

It follows from the above that every thirty degrees in azimuth have their joint or set of joints. Of these, the joints striking due east may well be compression joints, developed by the inward pressure toward the axial plane exerted by the limbs of the fold.

This quarry was first opened in 1882. It is now the property of the East Bangor Consolidated Slate Company, Inc., of East Bangor, Pa.

The products were roofing slate and slate for structural and sanitary purposes.

9. *Shimer Quarry.* The quarry lies about 300 feet northwest of the Consolidated No. 3 quarry. It is 300 feet long, 175 feet wide, being roughly rectangular and is probably 100 feet or more deep. The slate below this is inaccessible; hence only estimates of the dip and strike of the beds could be made; these appear to be N.40°W., 15°SW. The quarry is therefore in the same synclinal trough occupied by the Consolidated No. 3 and the Mountain View quarries, and operations were probably in much the same beds, the Gray bed probably having a depth of 40 feet below the surface.

This quarry has been idle for several years. The remnants of mill-stock on the dump look promising; no roofing slate was seen, but some was undoubtedly made here.

10. *Consolidated No. 2 Quarry.* The quarry is 500 feet southwest of the Consolidated No. 3 quarry and lies between that opening and the Consolidated No. 1—Star pit. The opening is almost rectangular and roughly 300 feet on the side, and 70 feet deep to the level of the water which stands in the deepest part.

The beds here are like those of the Consolidated No. 1—Star, but the strike has taken a sudden turn, so that it is N.40°W., with a dip westward in the west corner at the surface, although lower down the strike is N.30°W. The quarry is thus still in the synclinal trough mentioned in the description of the Shimer, Consolidated No. 3, and Mountain View quarries. The cleavage strikes N.85°E., and dips 23° (average) S. The grain trends N.40°W., dipping 70°-90°NE. Jointing is conspicuous. Two sets of joints are recognizable, one striking N.15°-35°E. and having very steep dips, the other striking N.35°W. (average), with dips of 50°-60°N. The strikes are very similar to the two main systems in the Consolidated No. 1—Star quarry, but the dip angles are different.

The quarry site was located by Bray and Short in 1865; 110 acres of land were bought for \$6,000 and operations were begun. Since about 1910, however, no slate has been quarried here.

The production consisted of structural and sanitary material and roofing slate.

11. *Consolidated No. 1—Star Quarry.* The large dump of this quarry is a conspicuous landmark at East Bangor. In area of surface opened, the hole is the second largest in the district. It is irregular in

form suggesting a rectangle 500 by 1,000 feet in size, but with a triangular promontory of slate projecting northward from the southern corner. The bottom of the quarry is extremely variable in depth, as the opening has been worked irregularly, now here, now there. In 1924, two working parts were maintained, one in about the middle of the southeast, the other along the northwest side. Both were about 70 feet below the surface.

A difficulty encountered in stripping the northern part of this quarry was the large quantity of glacial material overlying the slate. This overburden is 20 feet thick along the northwestern side of the quarry near the western corner, but thins to only three feet toward the south and decreases similarly eastward. Plate 1,B illustrates the heavy cover which had to be stripped off before the slate is reached.

Below the surface, after the beds to the south take a sharp turn, so as to dip southward at a steep angle (see description of Columbia Bangor quarry below), they resume a northward dip, which seems to flatten more and more as the beds are followed down the dip. It is these north-dipping beds that the Consolidated No. 1—Star quarry has exposed. These strike variously, an average of five observations along the southern working piece giving a strike of $N.32^{\circ}E.$, with a dip of $21^{\circ}N.$; the dip, however, suffers minor variations, in general declining northward, while the strike swings more nearly due north so as to become $N.20^{\circ}W.$ at the most northerly corner of the hole, with a dip of $7^{\circ}SW.$ In short, the structure presages the westward pitching synclinal axis mentioned in the Shimer, Mountain View, and Consolidated No. 3 quarries. A sketch map to show these changes in dip and strike is presented in Figure 58. The beds quarried are mainly those lying immediately above the Gray bed, which is itself to be seen in the southern working level, and outcrops again just south of the southeastern edge of the opening at the surface of the ground. The Middle big bed should be not far below the 1924 workings and is accessible in depth. At the northern working level the Black Ribbon bed is being worked and the Bangor Union big bed shows in the southwestern wall of the quarry, west of the southern working level of 1924.

The cleavage shows slight variations in strike and dip, but may be generalized as striking $N.80^{\circ}E.$, with a dip of $19^{\circ}S.$ The grain trends $N.40^{\circ}W.$, with a dip of $80^{\circ}E.$

Jointing is complex, as might be expected with the sharp turn of the bedding. In the Consolidated No. 2 quarry, the joints have been described as constituting two sets, one striking $N.15^{\circ}-35^{\circ}E.$, with steep dips, the other striking $N.35^{\circ}W.$ with northward dips of $50^{\circ}-60^{\circ}$. In the Consolidated No. 1—Star quarry similar strikes are seen, but the dips are not the same, both systems having steep dips in either direction. Most conspicuous are vertical joints having strikes of $N.30^{\circ}E.$, which are especially well developed on the northeast wall of the quarry (see Plate 10,B). A set of $N.65^{\circ}E.$ joints dip vertically, and generally ends at the intersection with joints of the $N.35^{\circ}E.$ set; it is suggested that the $N.65^{\circ}E.$ set is particularly related to the turn in the strike of the beds.

In the bottom of the quarry, which is now covered with waste, and in the northwestern corner there are places where calcareous beds show minute crumpling with the development of false cleavage. Here quar-

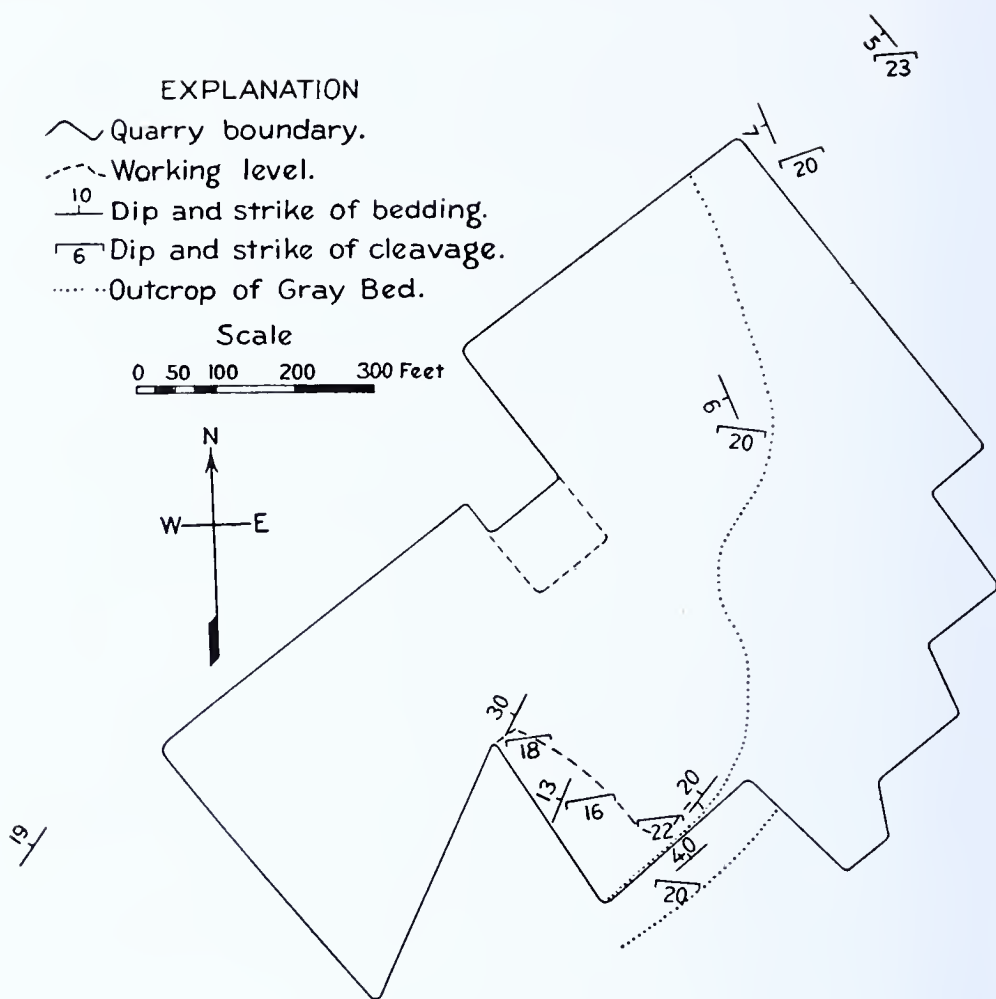


Fig. 58. Sketch map of Consolidated No. 1-Star quarry, to show northward change in strike of beds as synclinal axis is approached.

rying will probably prove unfavorable, as the regularity of cleavage in slate bearing false cleavage is generally reduced.

This quarry originally consisted of two separated parts, the eastern, formerly known as the Consolidated No. 1, and the western, smaller portion called the Star quarry. The eastern two-thirds of this quarry was opened about 1870.

Since 1868 the old Star quarry, which is the triangular, most western portion of the present opening, has been operated at intervals by various companies. Since 1919 the two openings have been united and operation of the resulting large quarry has been virtually continuous. In the beginning one of the main products was marbleized slate. The products now are roofing slate, structural and sanitary slate, and electrical slate.

12. *Standard Quarry.* This quarry, 200 feet west of the Consolidated No. 1—Star quarry, is 300 by 200 feet in plan; and at least 60 feet deep. Near the northern corner the strata strike N.45°E. and dip 22°NW.; in the middle of the southeastern side they strike N35°E. and dip 19°NW. No big beds are to be seen above the water level, but

the beds worked were undoubtedly the same as those exposed in the Consolidated No. 1—Star quarry, except that the Gray bed was probably encountered at greater depth. The cleavage strikes $N.78^{\circ}E.$, and dips $21^{\circ}S.$ The quarry has been long abandoned.

13. *Bangor Valley (Bangor Eclipse) Quarry.* This opening is about 3,500 feet due west of the town of East Bangor. It measures roughly 200 by 300 feet. Topographically it occupies a low position; the top of the hole is only about 30 feet above the creek. The depth is about 100 feet.

In the northern corner the beds strike $N.88^{\circ}W.$, dipping $10^{\circ}NE.$; virtually the same dip and strike are observable elsewhere in the walls. Presumably the beds are about the same as those in the Bangor Central quarry (see below), but the upper sections of the latter are probably missing because of the lower topographical position of the Bangor Valley quarry. No thicker beds were seen. In general, the cleavage strikes $N.59^{\circ}E.$, and dips about $25^{\circ}S.$, steepening slightly northward. Grain trends $N.45^{\circ}W.$ and is vertical.

Two systems of joints were noted striking respectively $N.55^{\circ}E.$, and due east; the former system can be subdivided again into joint planes dipping about $35^{\circ}S.$ and others dipping $50^{\circ}N.$ The joints that strike due east are vertical but are the less well marked of the two systems. These various types of joints are well seen on the northwest wall.

The quarry was operated until the beginning of the World War. Profit was obtained especially from quarrying the Mike Taylor bed.

14. *Bangor Central Quarry.* This lies 200 feet west of the Bangor Valley quarry. It is about 225 feet square.

The tal cover is as much as 25 feet thick, but varies greatly. At the surface the beds appear to dip $30^{\circ}S.$, with a strike of $N.60^{\circ}E.$ In the bottom the dips are northward and generally 4° to 5° , with strikes averaging $N.45^{\circ}E.$ The structure is thus continuous with that of the western side of the Consolidated No. 1—Star pit.

In the bottom of the quarry the sequence exposed is mainly that lying between the Thirteen big bed and Black Ribbon big bed; the Gray bed being encountered by deeper workings at the southern edge of the quarry. The Mike Taylor big bed was cut through at the very surface.

The cleavage dips 30° or so $SE.$ at the surface and has an average dip of 15° in the bottom, with a strike of $N.80^{\circ}E.$ Grain trends $N.65^{\circ}W.$, an unusually strong westward strike; the grain plane stands vertical. The low angle between the dip of the beds and the dip of the cleavage is favorable to a considerable "length" of slate along the cleavage, even though beds are somewhat thinner than usual.

Jointing in this quarry is exceptionally uniform. On the working level two joint sets were observed, of which one strikes due north, with dips of 50° or more, generally eastward; the other and dominant set strikes due east, with vertical dips. This constancy in joint systems is probably attributable to the fact that the nearest close fold—that in the Columbia Bangor—has a strike apparently at right angles to the direction of thrust in the slate folds, so that minor stresses with an oblique direction, such as would be exerted in the ends of pitching troughs, were not set up. In this opening also, the development of lenses of pyrite on the joint planes was observed. As far as can be recalled, these were seen

only in the joints striking due north. They are thin in their east-west dimensions, measure 0.1-0.2 inches vertically, are 0.3-0.4 inches long, and are clearly secondary.

The quarry was opened about sixty years ago, but a period of depression forced the suspension of work from 1885 to 1906.

In 1924 this quarry produced only roofing slate and wall slate, although millstock and electrical slate could well be made.

15. *Bangor Royal Quarry.* This opening, an elongated rectangle about 350 by 150 feet in size, and about 100 feet deep, is situated 200 feet west of the Bangor Central quarry.

At the north end of the quarry 40 feet of slate are exposed. This slate is nowhere accessible, but its strike appears about the same as in the Bangor Central, with a northward dip of approximately 7° . The attitude of the cleavage is similar to that in the Bangor Central quarry. Grain trends $N.45^{\circ}W.$ and dips vertically. A description of this opening appears in Sanders's¹ report on the slate region; it is described as having bedding dipping $N.40^{\circ}E.$ and cleavage $S.40^{\circ}W.$, but it is believed that the letters were reversed in the printing, the beds actually dipping $N.40^{\circ}W.$, and the cleavage $S.40^{\circ}E.$

The quarry has been abandoned for at least ten years. It was evidently already opened when visited by Sanders in 1874-78.

16. *Columbia Bangor-New Bangor Quarry.* This opening has been owned and operated by two separate companies. The east end is generally known as the Columbia Bangor (Ditchett's) quarry; the west end is frequently called the New Bangor quarry.

It is roughly a mile northeast of the postoffice at Bangor on the Portland highway. The opening is large and irregular in form. Measuring 800 by 400 feet, it is the third largest opening in the Bangor group. At the eastern end it has a maximum depth of about 125 feet. On the west end the maximum depth in 1927 was 100 feet. As the land surface slopes north, the quarry hole is deeper to the south.

This opening is the only one in which a direct clue to the structure underlying that shown in the Old Bangor is seen. It will be recalled that in the Bangor Central opening the beds dip gently northward. These beds, as they are followed up dip and southward, make a sharp turn where they are cut by the northwest wall of the Columbia Bangor. In the northwest and northeast walls, therefore, of the Columbia Bangor, there are shown the traces of a sharp syncline, the axial plane of which dips gently southward. Thus on the northeast wall at the surface the beds dip steeply southward, but change the direction in their downward course until they dip northward at an angle of 45° . The strike is $N.65^{\circ}E.$, and the bedding trace on this wall, which trends roughly normal to the strike, thus shows the true structure in the Columbia Bangor quarry. Followed westward, this fold passes into the northwest wall of the quarry. The projection of the bedding on the northwest quarry face is thus a flattened curve closing westward. Figure 59 illustrates the appearance of this feature as seen when looking down into the northern corner of the quarry from the southeast edge. As the structure is followed upward however, it gives place to a very close antiline, the upper limb of which forms the lower limb of the Old Bangor syncline. The axis of the antiline is nowhere

¹ Sanders, R. H., op. cit., p. 91.

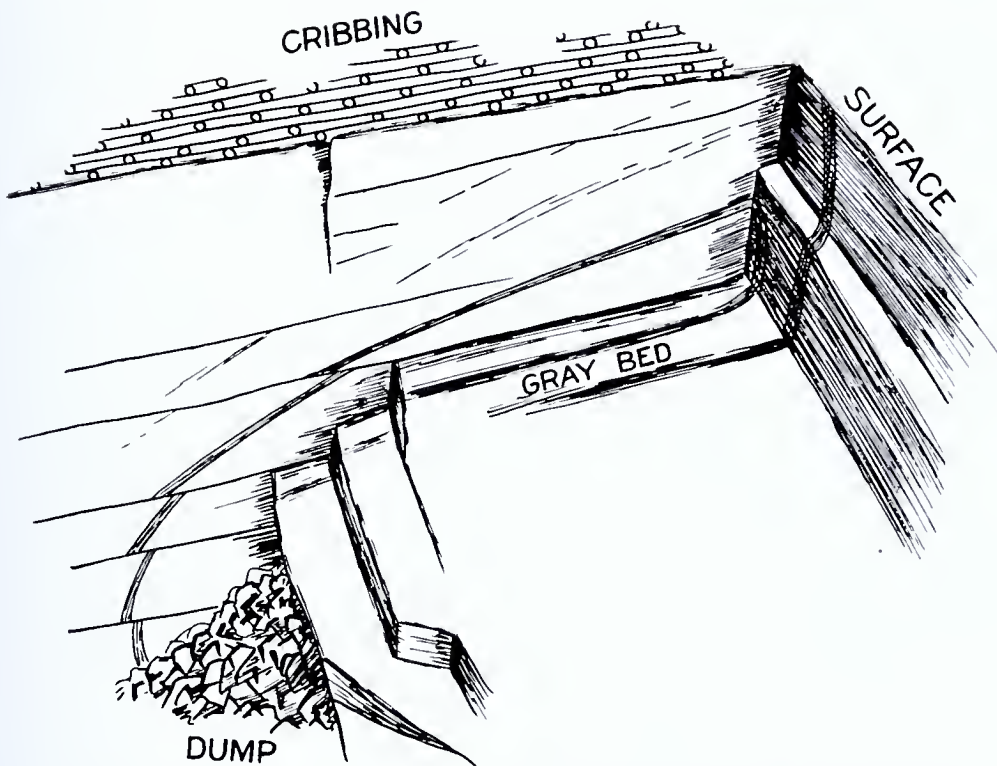


Fig. 59. Sketch of north corner of Columbia Bangor quarry to show projection of bedding on northwest and true dip on northeast wall; as seen from near the east corner of the opening.

shown, but is inferred from a comparison between the syncline seen in the northeast wall of the Columbia Bangor portion of the opening under discussion and the southwest wall of the New Bangor, which shows only a part of the upper limb of the antiline or what comes to the same thing, of the lower limb of the Old Bangor syncline (see Plate 44, BB'). It is thus apparent that there are in this quarry traces of two synclines and an anticline, all recumbent. This Columbia Bangor syncline may be regarded as a small drag fold on the under limb of the larger Old Bangor syncline to be mentioned later.

The beds exposed are the Gray bed and the sequence immediately to the south (i.e., below). The Middle (or Gray bed) big bed is to be seen in about the middle of the bottom of the Columbia Bangor portion of the hole. A remarkable feature is the great actual thickness of the beds.

The angle between the cleavage and the bedding, however, is so nearly 90° that the length of slate obtainable is scarcely greater than the actual thickness of the bed.

The cleavage in the Columbia Bangor part strikes $N.87^\circ W.$, and dips $15^\circ S.$, but in the New Bangor part of the quarry it strikes $N.45^\circ E.$, and dip $17^\circ S.$ Grain trends $N.45^\circ W.$ and is vertical.

Three systems of joints are recognized, both in the upper surface and below, on the southwest wall of the hole. These systems strike respectively (1) $N.40-65^\circ E.$, with dips of $40-75^\circ N.$; (2) $N.5^\circ W.-N.5^\circ E.$, with planes having curved surfaces, so that the angle of dip varies from 29° to $50^\circ E.$; and (3) $N.75^\circ E.-N.80^\circ W.$, with vertical planes. The

last system consists largely of a series of dominant joints striking due east, between which are small discontinuous joints striking more nearly N.80°W. The second system appears to be independent of the others. Joints of the third dominate those of the first system and cut across them without being offset themselves.

This quarry was already 80 feet deep in 1876. Since 1890 operations have been continuous in the eastern part of the opening, but intermittent in the western. In the past it has yielded roofing slate and millstock.

17. *Bangor Excelsior Quarry.* The northeast edge of this quarry is parallel to the southwest side of the New Bangor and is separated from it only by an inclined track. It is generally rectangular and 450 feet square. The depth is probably 150 feet.

Probably the beds strike generally N.35°E., as in the New Bangor to the east, and dip about 15°N. The structure is a continuation along the strike of the lower limb of the Old Bangor syncline (see below). The quarry was opened in beds immediately above (i. e., north of) the Gray bed, the Middle big bed doubtless being encountered at a depth of about 35 feet below the surface. Cleavage, as best it could be determined, strikes N.45°E. and dips 15°S. The grain trends N.50°W. and is vertical.

Joints seen are of three systems, all dipping approximately vertically and striking respectively N.30-40°E., N.80°E.-N.80°W., and N.60-65°W. The first and second apparently correspond to the first and last systems listed as occurring in the Columbia Bangor-New Bangor quarry, while the third has no counterpart in the New Bangor, unless indeed it represents only a slight variation in the strike of the N.80°E.-N.80°W. system.

The quarry was being operated when Sanders visited the region in 1874-78 but was not worked in recent years. The main production has been roofing slate, but also some millstock.

18. *Old Bangor Quarry.* This quarry lies half a mile east of Bangor. It is the third largest quarry in the district, roughly 1200 by 550 feet in its greatest dimensions. The form in ground plan, however, is very irregular.

The old bottom of the quarry is flooded, but the slate is exposed all along the southeast side, attaining a thickness of not less than 100 feet along the northeast and southeast sides. More recent work has been along the northeast side where a shelf had been cut down 60 feet below the surface by September, 1924.

The quarry exposes the Old Bangor syncline. This is a fold with an almost flat axial plane, the axis trending N.42°E. The fold is shown in its true relations on the northeast quarry wall, and here also it is seen that the upper limb dips more steeply than the lower, that, in short, the axial plane is not quite horizontal, but has instead a dip of 4°S.

As a part of the quarry is above, a part below the axis, the plane of which appears at the surface of the ground in the north corner of the hole, the dip of the beds is north or south at different levels in the quarry; even near the axis of the fold, however, the dip is generally lower than 30°. The appearance of a very flat syncline, with limbs diverging only 30° or so, which is seen in the southeast wall, is however,

PLATE 47.



A. View of mill, dump, and southeast wall of Old Bangor quarry;
from east corner of Bangor Union quarry.



B. East corner of Old Bangor quarry; looking N.60°E. from middle
of northwest side at the northward overturned Old Bangor syncline.

illusory and is caused by the small angle between the strike of the beds and the plane of this wall. The strike of the beds varies between $N.30^{\circ}$ and $62^{\circ}E.$ For further illustration, see Figure 60.

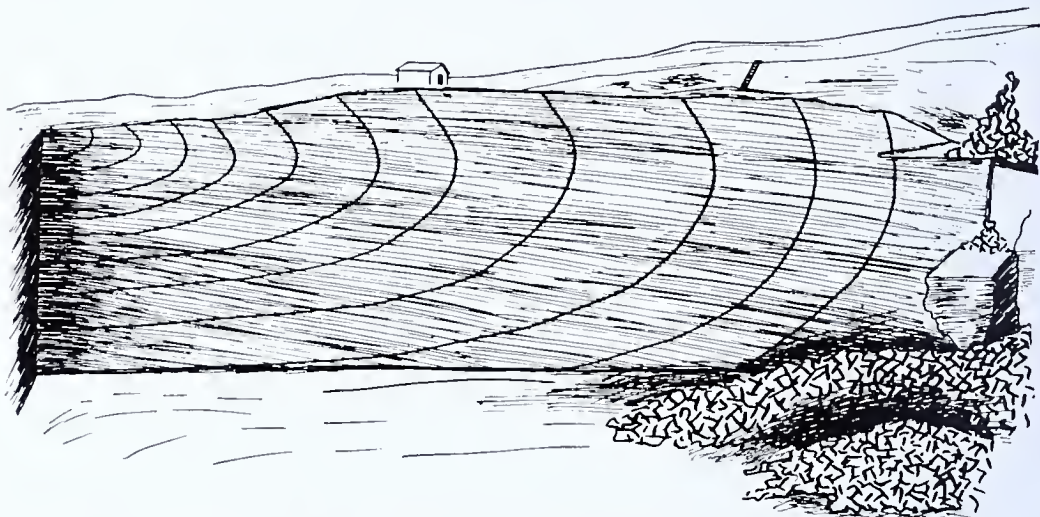


Fig. 60. Old Bangor syncline, viewed along the strike, as seen in the northeast wall of Old Bangor quarry.

The quarry has given its name, in the parlance of slate operators, to a series of beds generally spoken of as the Old Bangor "run". These include the sequence between the Thirteen big bed, which was quarried in the north corner along the axis of the fold, and the Nine Foot big bed, which is seen in the southeast wall and outcrops in the east corner. The Gray bed comes to the surface near the middle of the northeast edge of the hole. A series of sandy beds exposed at the east corner (where, because the sequence is overturned, they lie above the Nine Foot big bed) was encountered in the deepest parts of the quarry.

The cleavage strike varies between the same bearings as were given for the bedding, but it generally trends more nearly due east than does the latter; the dips are nearly horizontal, rarely exceeding 4° in either direction. The grain plane strikes $N.50^{\circ}W.$ and is vertical.

The jointing was studied in detail only on the small ledge of the present working level. Here four systems were recognized,—one striking $N.30^{\circ}W.$, with dips of $75^{\circ}N.$; a second striking generally due east, with vertical dips; a third striking $N.50^{\circ}-67^{\circ}E.$, with vertical dips; and a fourth striking $N.20^{\circ}-30^{\circ}E.$, with dips of $60^{\circ}-90^{\circ}S.$ All joints observed clearly fall into one of these systems. Of these the $N.30^{\circ}W.$ joints are rare.

There are thus two systems of joints very similar to those in the Bangor Exeelsior and Columbia Bangor-New Bangor quarries, one striking northeast, the other due east.

The hill on which the Old Bangor masts now stand was once the property of Philip Labar. Robert M. Jones, who has been called the founder of Bangor, first discovered slate there and, with Labar, opened the quarry in 1863. Since that time it has been worked sporadically. In 1924 it was sold to a new organization, the Amalgamated Slate Quarries Company of Easton, Pa. The quarry has an omnipresent problem in the disposal of waste, which is now being thrown into the

old hole or earried south uphill. The production is mostly roofing slate, but millstoeck has been produced at intervals.

A photograph of the dump, plant, and opening is shown in Plate 47,A.

19. *North Bangor No. 3 Quarry.* This lies 200 feet north of the northeast corner of the North Bangor quarry, described below. It is 320 by 100 feet in plan and was about 65 feet deep in 1924.

The beds at the surfaee strike N.63°E. and dip 35°-40°S., but in the bottom they turn so as to dip 40°N. The structure is thus a northward overturned syncline, the axial plane of which dips south 8° and, to judge by the cleavage, strikes N.80°E. Although this axis is thus considerably above the axis in the North Bangor quarry, it is clearly a part of the same structure, for quarrymen insist that between the two openings all beds dip south at the surface.

In the North Bangor No. 3 quarry there are two big beds, the more northerly of which is called in this report the North Bangor No. 3 First big bed, while the lower and more southerly is the North Bangor No. 3 Second big bed; quarrymen do not use the terms "First" and "Second," having had little oecasion to mention the two separately. The first bed is 7½ feet thick, the second 4½ feet thick; each has a prominent "hard roll" (sandy base). The two are separated by 15 feet of ribboned slate. Both big beds are exposed at the surface and can be seen in the northeast wall all the way down to the present working level. They are shown in the sketch, Figure 61, which represents a view of the northeast wall from the surfaee on the opposite side; the angle of dip of the beds in this sketch is slightly exaggerated.

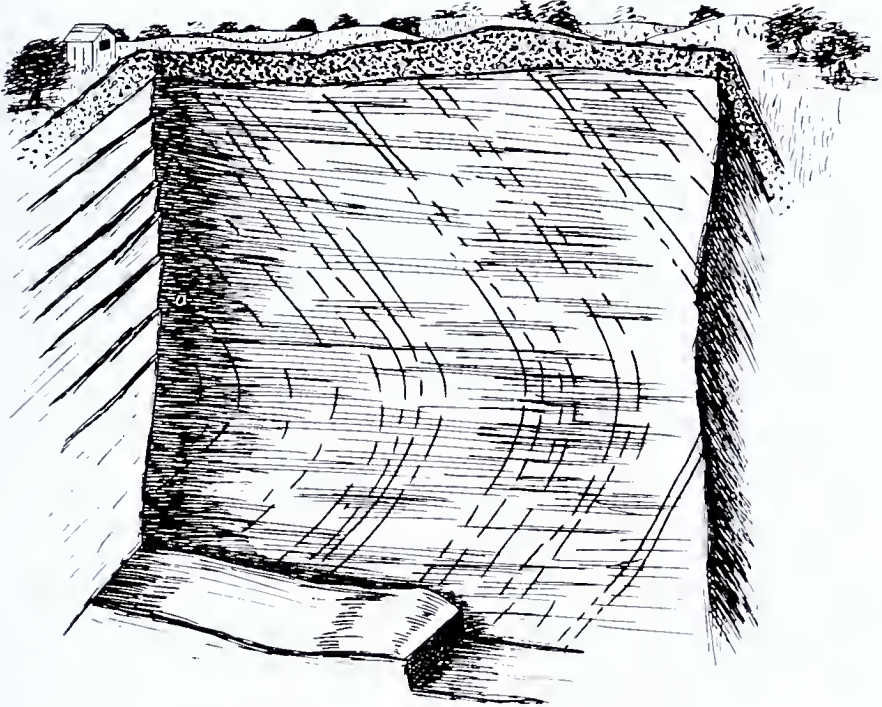


Fig. 61. Old Bangor syncline, as seen in the northeast wall of the North Bangor No. 3 quarry; the dip is slightly increased through foreshortening.



A. Upper part of northeast wall of North Bangor quarry, as seen from middle of southwest side; the trace of the Old Bangor syncline is suggested; the big bed to the right (south) of A is the Mike Taylor big bed.



B. Northeast side of Northampton quarry at Bangor as viewed across the opening; typical bedding slip fault in center, the crushed fault zone being at A; closely spaced joints are seen to the right (south) of A.

The cleavage strikes generally N.80°E. and dips 10°-20°S., with a tendency to decrease upward. Grain trends N.48°W. and is vertical. Jointing is of two systems: (1) strike N.80°-85°E., dip vertical; (2) strike N.10°W., dip 40°NE.

This quarry was open when visited by Sanders¹ in 1874-78. Since then the history has been closely linked with that of the North Bangor quarry and with the North Bangor No. 2, which lay between the two other openings but is now hidden by waste. Operations in the North Bangor No. 3 have been discontinued several times. In 1924 it was reopened. Products include roofing slate, structural and sanitary material, electrical slate, and slate for blackboards.

20. *North Bangor No. 1 (North Bangor) Quarry.* The opening is on the ridge between the main valley of Martins Creek and its east branch. It is 400 by 250 feet in plan and 330 feet at its greatest depth. From Bangor its dump is the first to be seen on this ridge.

An overburden of 20 feet of glacial clay and boulders occurs here.

The quarry exposes a portion of the structure seen in the Old Bangor and North Bangor No. 3 openings. The beds at the surface dip 25°S., but 65 feet lower they are vertical and 185 feet still lower they dip 10°N., the average strike being N.29°E. The fold thus shown has an axial plane striking about N.60°E. and dipping 9°S., and is well seen in the northeast side of the hole, a photograph of which is given in Plate 48, A. In comparison with its position in the Old Bangor quarry, the synclinal axis has an easterly bearing, for in the Old Bangor opening the axial plane strikes N.42°E.

The beds exposed in this quarry are placed by the quarrymen in the North Bangor "run." They include two big beds, one of which is unnamed and which it is proposed to call the North Bangor big bed; this is about 7 feet thick. The other, the Mike Taylor big bed (see on Plate 48, A), is about 8 feet thick. South of and 50 feet below this in actual thickness of beds lies a smaller big bed, with a heavy "hard roll", the two together being about 4 feet thick. This latter bed outcrops at the extreme east corner of the quarry dipping south, and appeared again in the deeper part of the old opening, which is now waste-filled, dipping north.

The cleavage strikes N.80°E. and dips generally 9°S. Grain trends N.54°W. and is vertical. The joints observed are of two systems: the strikes are N.32°E. and N.70°E.; joints of the former set dip 55-80°E., of the latter vertically. One joint strikes N.15°E., and dips 70°S. In general, the joints stop at certain "sparry ribbons." These "ribbons" are slickensided, which indicates that the movement along them in part relieved the pressure to which these joints are due.

This quarry has had a long and interesting history. It was opened in 1862 by John Brown, who operated it until 1883 when it changed hands; from then until the present it has been in almost continuous operation.

Of special interest here is the yield of school slate. Most other types of slate products—roofing slate, sanitary and structural materials, blackboards, and electrical slate—are obtained from this quarry. Roofing slate is stored outdoors.

21. *Bangor Union Quarry.* This opening is a quarter of a mile

¹ Sanders, R. H., op. cit., p. 92.

northeast of the post office at Bangor. It is roughly rectangular and 550 by 400 feet in size. Its greatest depth now is 230 feet, but it has been largely filled with waste. Since 1923 operations have been confined to the southwest of the larger opening. The property line between this and the North Bangor quarry lies generally along the sharp wall which separates the two main openings.

This quarry is in beds lying stratigraphically just below those exposed in the North Bangor quarry and slightly farther east along the strike, so that the beds and structure in the Bangor Union may be said to begin where those of the North Bangor leave off. The strata at the surface dip 20° S., with strike averaging $N.70^{\circ}$ E.; 100 feet below the surface they strike $N.34^{\circ}$ E., dipping 13° N. in the south corner of the quarry. The syncline, resembling its appearance at the North Bangor quarry, is cut by the somewhat curved quarry wall in the northwest edge of the opening. The strike of the axis is about $N.65^{\circ}$ E. This "tight" fold with some slight undulations in the axial plane, produces, when cut by the southwest quarry wall, the appearance of a wedge with a very sharply pointed apex. The slate in the southwest wall of the opening includes three big beds, which, in the order named are, from top to bottom, the Bangor Union big bed, the Black Ribbon big bed (also called the Balmoral big bed) and the Thirteen big bed. The same order, obviously, holds from north to south at the surface.

The cleavage strike varies greatly, but is generally $N.60^{\circ}$ E., with a southward dip of less than 10° . Grain trends $N.50^{\circ}$ W., and is vertical. Beneath the axial plane of the fold, joints striking $N.50-55^{\circ}$ E. are seen dipping vertically. Near the axis joints striking $N.60-70^{\circ}$ E. are developed, apparently of the same system, also vertical and generally tangent to the beds. These are complementary with a set of $N.65-90^{\circ}$ W. joints, which branch off from the northeast striking joints. A third set strikes $N.10-35^{\circ}$ W., with vertical dips; these are small, and apparently tensional products at right angles to the line of compression expressed by the $N.60^{\circ}$ E. joints. There are thus three systems, all vertical and striking respectively; (1) $N.50-70^{\circ}$ E., (2) $N.65-90^{\circ}$ W., (3) $N.10-35^{\circ}$ W. This yields a pattern closely resembling that of the Old Bangor quarry.

This quarry has been in operation since about 1870. The principal yield is roofing slate, but much milled slate is also produced.

22. *Bangor Washington Quarry.* The opening is 1200 feet northeast of the Bangor post office, on the east side of the State highway. In 1923 it measured 225 by 400 feet but has since been enlarged through stripping.

The beds exposed in the old pit were mainly those on either side of the Gray bed, which, it is said, was to be seen near the middle of the northeast side of the hole. The beds here are on the lower (i.e., originally the north) limb of the recumbent syncline described in the Old Bangor quarry. The upper (or south) limb has been eroded, leaving the beds practically vertical along the southeast wall of the quarry, but with a rapidly declining dip to the north as the northwest wall is approached. The southeast wall of the quarry is thus on the axis of the fold at the surface. In general, the strike of the beds is $N.50-60^{\circ}$ E. Cleavage planes are not accessible, but appear to dip gently south with the same strike as the beds. Prominent joints in the southeast corner strike $N.68^{\circ}$ E. and dip 45° S.

Slate was first quarried here by Philip Labar in 1868. The property was then sold to Fulmer and Wagner, who worked the quarry for a short time. With periods of idleness it was operated until 1905. Since then it has been shut down most of the time.

For many years roofing slate and school slate were made, but as the school slate industry declined this phase of production was discontinued. Since 1895 only roofing slate has been produced.

23. *Northampton Quarry.* This quarry is well separated from the other openings of the Bangor Group, being about $1\frac{1}{2}$ miles north of the Bangor post office and less than a mile from Roseto. It is about 250 feet square, and was 230 feet deep in 1924.

The slate in the northern corner is covered with 12 feet of glacial clay and boulders.

In general the quarry shows bedding standing almost vertical at the surface, but decreasing in dip with increased depth; this decrease is accompanied by a reversal, for at the surface the beds, if not upright, dip north, while below they dip south. The fold thus seen is, so far as exposed in the quarry wall, very "open," with but little thickening along the axis. The average bedding strike is $N.58^{\circ}E.$

There is much dispute in regard to the correlation of these beds. Among the quarrymen generally it is believed that the slate is of the Diamond "run" in the Pen Argyl beds. This belief rests on two observations: first, the slate is "soft" and easily shattered, resembling in this respect the beds worked in the Diamond "run" at Pen Argyl; second, the observer, standing on the dump between the old Diamond and the United States quarries at Pen Argyl and sighting eastward in line with the compass direction of the outcrop of the Diamond "run," is looking in the general direction of the Northampton quarry. Against these two lines of evidence, other facts may be cited. First, it is apparently true that all slate so far encountered lying north of (that is, above) the beds opened in the Diamond quarry at Pen Argyl is "softer" than that lower down in the sequence; thus, the slate in the Fidelity and West Bangor quarries is of this character. Second, there is no actual correlation, bed for bed, between the sequence in the Diamond "run" and that in the Northampton quarry. Accurate measurements of the sequence in the Doney, New Diamond, and Parsons quarries, compared with that in the Northampton, do not clearly establish any correlation. Third, there is good evidence, as will be seen from what is said below, in the description of the Pen Argyl quarries, that the beds take a marked northward turn as they are followed east from Pen Argyl; if anything, therefore, sighting eastward along the strike of the beds at Pen Argyl is almost certain to carry one into lower, more southerly beds.

Mr. Spry of Bangor, on the other hand, assigned the beds of the Northampton quarry to the Acme "run" as exposed in the Acme quarry at Alpha, west of Pen Argyl. Certainly as much can be said for this correlation as for the one more commonly held. The measurements, in the opinion of the writer, favor this correlation if any. The big bed exposed near the south edge of the lowest working level in the Northampton quarry would correspond to the second big bed from the south edge of the Acme quarry's top piece. If this correlation is correct, the Northampton property should contain the Albion beds and a trench cut 60 feet at right angles to the strike from the northwest

edge of the present hole should just reach the Hard Front big bed. The data so far obtained, however, do not finally establish the correlation between the beds in this and other quarries.

Three big beds are worked in this quarry. On the upper level a bed 82 inches thick, yielding a length of 86 inches along the cleavage and with a thickness of 33 inches of "hard roll," is profitably worked. Farther south and on the lower level are other big beds, the northern having a thickness of 64 inches, with a 9 inch "hard roll," the second with a 97-inch thickness and a "hard roll" of 15 inches. Of the three big beds enumerated, the northern (upper) corresponds most nearly to the Red bed of the Diamond "run," if it is to be at all correlated with a bed of the Pen Argyl group. It bears a conspicuous "hard roll," in which the cross-bedding has a marked west dip.

The jointing in this quarry follows two general systems, one trending N.60°E., with dips of 45-50°N., the other N.60°W., with southward dips of 45°. The northeast joints are the more conspicuous. One of the northwest joints bears lenticular depressions similar to those of the Bangor Central and other quarries. Minor joints that do not fit any of these systems are also seen.

Near the middle of the northeast wall of the quarry on the lowest level there is a thick calcareous and chloritic stratum. This consists in detail of two calcareous beds, each about an inch wide, heavily fractured and separated by a chloritic layer which has a maximum thickness of two inches. The chloritic band narrows here and there, whereupon the two calcareous beds come together, separating again as the chlorite widens.

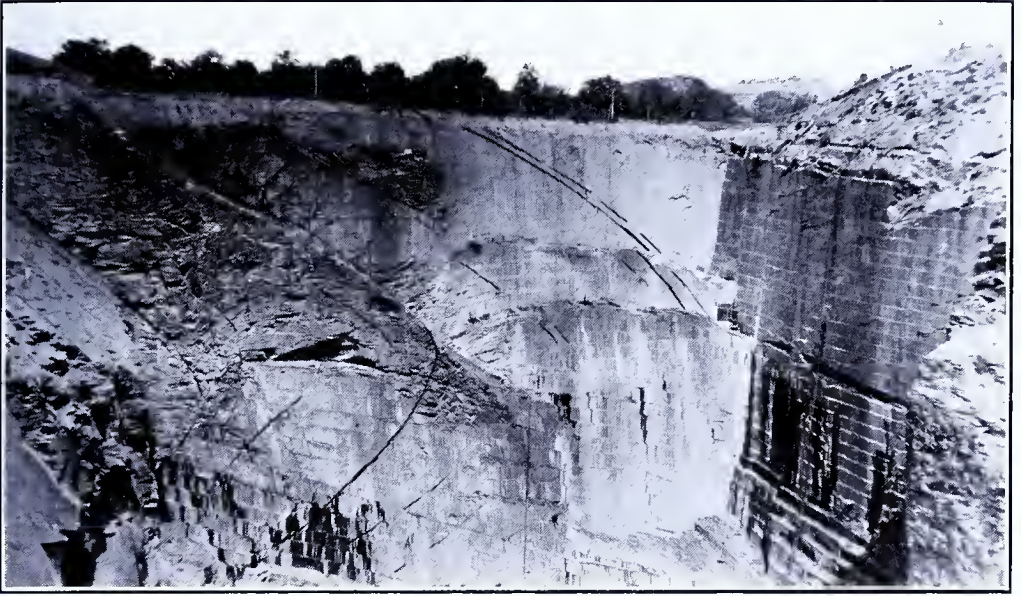
In the northeast wall there is a bedding slip fault, similar to that described in the New Peerless (Bangor vein) quarry. In this instance joints are again developed along the fault and the cleavage has been severely distorted, making quarrying immediately along the fault plane not only profitless but dangerous. A discussion of this type of fault has already been given (see page 166). Although the feature mentioned adds expense to the operations, the slate 30 feet north and south of the fault plane seems wholly acceptable as structural material. The fault is illustrated in Plate 48, B.

The Northampton quarry was opened in 1885. With intervals, operations have continued under various managements until the present. The products are blackboards, millstock, and roofing slate. All three of the big beds are used for blackboards. Electrical slate comes largely from the big beds and from several small beds close to the northernmost of these.

24. Shaft on Blake's Property. This is a small vertical shaft 60 feet deep about half a mile west of the Bangor post office and 400 feet south of the Bangor-Pen Argyl highway.

The beds found are said to have been about the bottom of the Bangor "run;" it is said that the 9-Foot big bed could be identified. The cleavage dipped south; blocks of the slate found on the surface were properly oriented (assuming a grain strike of N.40°W.) and the bedding strike was thus determined to be N.70°E.; the exact inclination of the bedding could not be determined, but it is gently northward.

PLATE 49.



A. Folding and bedding slip plane in Albion quarry as seen from the middle of the southwest side; the bedding slip plane is at the northeast (left) edge.



B. Northeast wall and 380-foot level of the Parsons quarry,—the deepest in the United States; regular joints are seen on the northwest (left) wall, which is formed by a "loose ribbon." Photograph by Bliss, Easton, Pa.

WIND GAP—PEN ARGYL GROUP.

The quarries of the Wind Gap and Pen Argyl group center around these two towns and quarrymen secure their supplies there. Pen Argyl was, in fact, primarily dependent on the slate industry, although shops of the Lehigh & New England Railroad at Alpha absorb some labor from the town in normal times. Men employed in a few of the quarries that lie nearer the outskirts of this natural grouping might normally trade in Bangor or Factoryville.

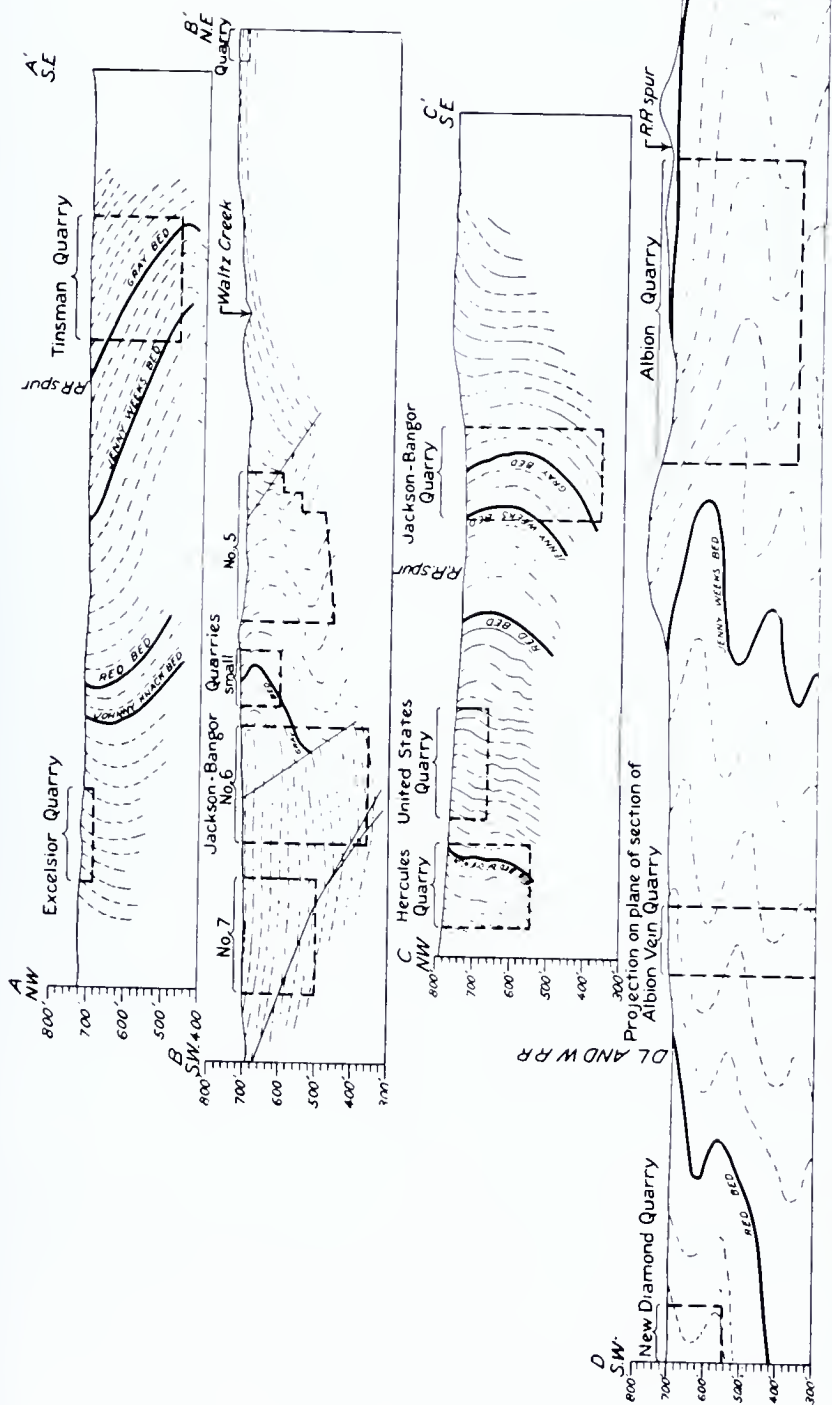
Like the quarries of the Bangor group, the operations at Wind Gap and Pen Argyl are in the soft belt. The upper part of the upper member of the Martinsburg is called the Pen Argyl beds, from the fact that it is exposed in the quarries in this group. The minor subdivisions or "runs" are named after the older quarries at Pen Argyl, hence such names as Acme, Phoenix, Albion, Diamond, and United States "runs." The strip of Pen Argyl beds, including the runs mentioned and others, is readily identified at the Albion Bangor quarry and can be traced eastward, in a nearly straight line, with only slight flexures, as far as the Jackson Bangor No. 5 (Valley) quarry. Farther east the correlations are either uncertain or the statements of old quarrymen must be accepted, in the absence of accessible quarries in which the beds can be measured. Thus the correlation of the beds in the Northampton, New York, and Hoboken quarries, of the Bangor group of quarries, is in doubt, as already indicated.

Were the correlations merely a matter of sighting eastward or westward along the strike of the "ribbons" or beds, it would not be difficult to establish the exact stratigraphic position of a quarry site in advance of operations. But in the quarries of this group the effect of topographic elevation on the outcrop of a bed is again a complicating factor, for the strata are thrown into folds which, though open, nevertheless attain dips as low as 30° on the limbs (see Plate 50).

From the Albion Bangor eastward to the Tinsman quarry it is apparent that the surface structure on which the greater part of the openings are located is the south limb of an overturned syncline the axial plane of which dips south. From the Phoenix to the Acme and Alpha quarries the strata exposed at the surface dip north on the north limb of the same syncline. In the Doney, Diamond, Albion Vein, Albion, and Jackson Bangor No. 7, 6 and 5 pits the strata dip south at the surface and the structural position of these openings is thus similar to that just mentioned for the Albion Bangor quarry. In some quarries, such as the Albion Vein, several small folds are encountered as successive depths are attained. It is highly probable that these structures all pitch west.

The cleavage commonly dips south, but rarely (as in the Albion quarry) inclines to the north. It is generally fairly regular, although in a few places, near surfaces along which movement has taken place, cleavage planes are so badly warped as to preclude the use of the slate affected.

There is faulting of various kinds in these openings. Bedding slip faults, already mentioned as occurring in such quarries of the Bangor group as the New Peerless quarry, are found at Pen Argyl; further, an unusual type of fault plane, striking northwest, dipping northeast, and along which displacements of as much as 125 feet in the direction of movement are recorded, is not uncommon.



Structure sections in Wind Gap-Pen Argyl region; scale 1 inch=600 feet. AA' Section N.20°W. through Tinsman quarry; BB' Section N. 70°E. through Jackson Bangor Nos. 5, 6, and 7 quarries; CC' Section N.25°W. through west edge of Jackson Bangor No. 6 and Hercules quarries; DD' Section N.65°E. through New Diamond and Jackson Bangor No. 7 quarries.

For the most part joints in these quarries strike approximately parallel with the cleavage, but no further generalizations can be made. The close resemblance between joint systems in quarries that lie near each other is again noteworthy.

The products of the quarries of this group are varied, and include all the articles commonly made from slate except peneils. Quarries opened in beds above the Pennsylvania "run" or below the Albion "run" generally find the production of structural, electrical, and blackboard slate more profitable, and make roofing slate in smaller quantities only, if at all.

At the time of these studies seventeen quarries were operating in this group. Some are very large, others of only moderate size. The district includes the Parsons opening, the deepest slate quarry in the United States.

1. *Nungesser Quarry.* This opening is on what is known as the old Nungesser property about two miles S.60°W. from the post office at Wind Gap. The opening measures 50 by 70 feet and has a depth of 20 feet. Two big beds and several smaller ones, all conspicuously sandy, are seen. The strata strike N.53°E. and dip 9°S. at the south end of the quarry, but the dip steepens to 38° at the north. The cleavage strikes N.53°E. and dips more steeply than the bedding, so that a southward overturn is actually suggested.

This quarry was opened about 40 years ago but no slate has been removed in the last 20 years. Millstock and roofing material were the products.

2. *Albion Bangor Quarry.* This quarry is the farthest west of those operating in the Pen Argyl region. It is half a mile west of Rismiller station on the now abandoned Lehigh New England spur west of Wind Gap. The main hole measures 300 by 200 feet; the lowest level is about 180 feet below the surface of the ground.

There is a strikingly heavy overburden of glacial material above the slate, reaching a thickness of 35 feet.

The beds in the northern corner of the opening strike N.70°E. and dip 53°S. at the surface, but in the southeast part the dip steepens to 80°S. at a depth of 30 feet below the surface. It follows that an axis is being approached southward. The dip of the beds should thus decrease as they are traced downward from the surface along the south wall of the quarry. In accord with this interpretation the dip in the lowest level is approximately 43°S.

This quarry apparently exposes beds north of (i. e., above) beds of the New Diamond and Parsons quarries. A thick bed, probably the equivalent of one of the big beds of the Diamond "run," crops at the surface about ten feet north of the southwest corner. The calcareous ribbon occurring along the north side of the Parsons quarry, in the Albion Bangor quarry comes to the surface about 45 feet north of the southwest corner. About 115 feet in actual thickness of beds are exposed; these are mainly strata not shown in other operating quarries. There are several big beds, of which the most conspicuous measures five feet in thickness with an additional four-inch sandy layer at the south (lower) end.

The cleavage strikes about N.73°E., and dips 18-25°S., a rather high angle. Grain trends N.47°W. and is generally vertical. The joints

in this quarry have a conspicuous easterly direction and either parallel the strike or form small angles with it, dipping gently north. These joints, together with the cleavage openings, serve as courses for water, although some also enters through the openings formed by solution along carcarous beds.

This quarry, also known as the Blue Mountain quarry, was opened in 1895 and worked until 1924. In that year the property was offered for sale and since then its history has not been followed. The yield in the past has included electrical, roofing, and structural slate, as well as blackboards. In recent years, however, structural material alone has been produced.

3. *Arvon Quarry.* This opening measuring about 300 feet on each side, is separated from the Albion Bangor quarry just described by a strip of ground only 30 feet wide.

An overburden of glacial material similar to that at the Albion Bangor covers the slate here. The axis predicted in the south part of the Albion Bangor opening actually becomes visible in the southwest corner of the Arvon quarry. Here the beds dip 60° N. (estimated) 25 feet below the surface and dip vertically an equal distance deeper. The axis of the fold thus defined strikes northeast and dips south 25° ; along the north edge of the quarry, however, the beds strike $N.74^{\circ}$ E. and dip 55° S. The dip diminishes progressively with depth on this side of the quarry, as might be anticipated from thinning of beds on the limb of the structure described.

The beds are the same as in the Albion Bangor quarry; this is to be expected, as the Arvon lies along the strike from the other opening. However, a portion of the workings of the Arvon must be in the same beds as the top "piece" of Parsons quarry if the correlation advanced above between the beds of the Albion Bangor and Parsons quarry be correct. The present opening of the Arvon thus exposes a greater thickness than does the Albion Bangor quarry. The beds thicken notably as they approach the surface.

Cleavage is fairly uniform. It strikes $N.73^{\circ}$ E., with average dips of 24° S. Grain trends $N.38^{\circ}$ W., and dips $75-90^{\circ}$ W. The joints observed fall into two systems, one striking $N.70^{\circ}$ E., and dipping $6-10^{\circ}$ S. (spoken of as "floors" by the quarrymen) and a second striking roughly east, and dipping 45° N., but irregular. The feature called "catspaws" (see page 46) by the quarrymen was observed in this quarry.

This quarry was opened in 1911 but in recent years operation has been intermittent. The products are roofing slate, blackboards, structural material and a little electrical slate. There are generally too many "knots" in the slate to make the production of much electrical material practical.

4. *Excelsior Quarry.* This opening is half a mile west of the Wind Gap post office. It is almost square, measuring roughly 200 feet in each dimension. The depth below water level is not known.

The slate is covered with two feet of clay and boulders.

The beds appear to strike variously,—approximately $N.45-65^{\circ}$ E. though these bearings are estimates only. The dip averages 57° N. The structure thus represents a continuation of that in the Arvon

quarry in the east wall. With depth the beds will approach a vertical dip, and then gradually reverse until they incline southward.

The most reasonable interpretation of the structure between this opening and the Tinsman quarry, in which the Gray bed of the Albion "run" is seen, leads to the conclusion that the operations in the Excelsior were yielding slate from the Diamond "run." This interpretation is in accord with the commonly expressed views of quarrymen. The cleavage strikes N.62°E. with dips of 40°S. The grain trends N.45°W., and stands vertical.

This quarry was first operated from 1900 until 1920, when it was shut down. Operations were resumed in 1927. The products include some roofing slate, as well as blackboard and structural material.

5. *Pelican Quarry.* This quarry is about half a mile east of Rismiller, on the south side of the main highway between Rismiller and Wind Gap. It measures roughly 150 by 300 feet and is at least 60 feet deep to water level.

The beds opened are said to have been the Acme "run" near the surface, but probably, as in the case of the Tinsman quarry, the Albion "run" appeared below the present water level. The strike and dip of the strata are N.80°E. and 39°S., but toward the south there is a steepening to a dip of 42°S. Cleavage strikes due east and dips 28°S. Grain trends N.40°W. and dips 28°S. Several N.50-55°E. joints dip 75°N. at the surface but become more vertical with depth. Judging by the material on the dump, the products were mill stock and roofing slate.

6. *Tinsman Quarry.* This quarry lies about 600 feet east of that just described and on the north side of the highway. It is a nearly square opening, 300 feet on each side, with a depth of 245 feet.

The glacial overburden attains a maximum thickness of about 15 feet. The quarry is opened in the Acme "run," but at a depth of about 50 feet on the north wall the Gray bed of the Albion "run" appears. The lowest workings in 1927 were well above (stratigraphically) the Gray bed.

The structure in which the opening is made is the lower limb of a northward overturned anticline having an almost horizontal axis. The beds at the surface strike N.75°E., and dip 37°S., while in the bottom of the quarry the strike is N.73°E., and the dip 32°S., a decrease in dip with depth, whereas the cleavage dips more gently than the beds. This structure is complicated by transverse folding, however, for both at the surface and in the lowest part of the hole, the beds along the east wall strike N.73-75°E., whereas on the west side they strike N.88-75°W. As the strikes of both beds and cleavage take this turn, there is a suggestion that the transverse folding was accomplished in part later than the development of the slaty cleavage, possibly by much movement along the open bedding planes. Cleavage dips 20° south. The grain trends N.50°W., and dips uniformly about 70°E. The joints do not well fall into any single system, but possess rather a radial pattern, such as might be expected if the transverse folding mentioned had been induced more recently than the cleavage; see Figure 17 B.

This quarry, also called the Penn-Bangor, was first opened in 1901, and, with occasional interruptions, was still operating in 1927. The production included roofing, blackboard, structural and electrical slate.

7. *Allen Quarry.* This opening is 3,000 feet almost due south of the Wind Gap post office and 800 feet east of the Nazareth-Wind Gap highway. It is about 60 feet square.

The beds are reputed to be in the Grand Central "run." They strike N.65°E. and dip 85°S., but the dip flattens downward, diminishing to 60° in a vertical distance of only four feet. This suggests that the exposure is on the south limb of a northward overturned syncline. The cleavage strikes N.80°E., and dips 20°S. The grain trends N.37°W., with an eastward inclination of 80°.

The quarry was last worked about 1912. It yielded good roofing slate, though no big beds were found.

8. *Kinney Quarry.* This small opening lies about 1200 feet S.80°E. from the Woodley House in Wind Gap. It is approximately 80 feet square and 35 feet deep.

Mr. Kinney of Wind Gap, the present owner of the property, who opened the quarry, says the beds exposed were supposed to be in the North Bangor No. 3 "run." Two big beds were encountered, of which each was 12 to 13 feet "long," measured along the cleavage plane, the two being separated by 18 to 20 feet of thin beds,—a sequence corresponding moderately closely with that of the North Bangor No. 3 beds as measured at Bangor. The beds strike N.70°E. at the surface and dip 43°S. The cleavage strike is N.73°E., and the dip is 18°S.; the structure thus appears to be on the south limb of a syncline with southward dipping axial plane.

This quarry was opened about 1907 and only roofing slate was produced.

9. *Phoenix Quarry.* This quarry is at Wind Gap about 1,200 feet east of the highway and half a mile south of Alpha. It is 350 by 200 feet in size. The lowest level had a depth of 260 feet in 1927 and there are several sub-levels on its west side.

Cutting through a shallow overburden of weathered slate and till, this quarry is opened in beds that lie south of (i. e., under) the Acme "run." At least three big beds are found, each over 4 feet thick.

At the surface the beds strike N.78°E.; they dip vertically along the south side of the quarry, 68°NW. along the north edge. Downward they decrease in dip to 38° but retain their northward inclination. The structure is that of the north limb of a syncline, the axial plane of which emerges near the south edge of the opening and dips south at an angle estimated to be 15°. Cleavage strikes are almost uniformly N.70-72°E. The grain trends N.57°W. and is vertical. The predominance of N.60-80°E. joints having steep dips is very conspicuous.

The quarry is operated by the Phoenix Slate Co., of Wind Gap and was opened about 1890. Many small operators worked the property in turn, but in 1907 it passed into the hands of the present owners. The product consists almost wholly of milled material, including especially large quantities of billiard table tops.

10. *Heller Quarry.* A small pit lies 700 feet north of the Phoenix quarry, across the road from the latter. It is about 70 feet square and 50 feet deep.

Several slate men assert that the opening exposes part of the Albion

beds, as might be expected; Mr. Spry of Bangor says it yielded the Front big bed. The strata strike $N.78^{\circ}E.$, and dip $75^{\circ}NW.$ at the water level. At the very surface they appear to stand vertical, as though the axial plane of the fold seen in the Phoenix quarry were almost horizontal.

This quarry, truly little more than a prospect, produced a small quantity of roofing slate.

11. Imperial Quarry. This large quarry is half a mile east of Wind Gap and 2000 feet south of Alpha. It measures 400 feet in each direction. In 1927 it was being reopened over a larger area. The depth is uncertain.

The beds worked are like those in the Phoenix quarry, as the two quarries lie along the same line of strike; the same three big beds are worked. In the Imperial quarry they strike $N.70^{\circ}E.$, and dip $45^{\circ}SE.$ in the northeast corner, but the turn in dip is apparently so sharp that in the northwest corner the dip is to the northwest. At the south corner the beds are vertical and 40 feet lower they dip $60^{\circ}N.$ The syncline thus shown fits in with the structure seen in the Phoenix quarry, where the surface of the ground does not quite rise to the level of the axial plane. In the northeast corner of the quarry the cleavage strikes parallel with the beds and dips $20^{\circ}S.$ Grain trends $N.57^{\circ}W.$

From 1905 to 1911 this quarry was actively operated. Thereafter it remained idle until 1926 when operations were resumed with stripping along the east side. The main production consists of structural slate, blackboards, electrical, and roofing slate.

12. Acme Quarry. This is the more southerly of the two quarries located about 1,250 feet due southeast of the Alpha station. It is an elongated rhomboid in ground plan, dimensions being about 400 by 200 feet. The bottom of the lowest level has a depth of 105 feet.

In the Acme quarry the beds worked constitute the Acme "run" and correspond in part to those of the upper part of the Tinsman quarry. They are softer than many of the other beds of the Albion quarries. Toward the southern edge of this sequence are two exceptionally big beds, the more southerly of which is used for blackboards and electrical slate, while that to the north makes excellent blackboards and structural material.

At the surface the beds dip $85^{\circ}S.$, and strike $N.70^{\circ}E.$, but as they are followed northward the dip becomes $80^{\circ}NW.$ In the upper level a change to the same effect is observed; the beds at the southern edge of the level dip $85^{\circ}N.$, although those in the northern part dip only $46^{\circ}N.$ It is clear from these observations that the quarry is on the upper (south) limb of a northward overturned syncline, continuous with the structure described in the Phoenix quarry. Cleavage varies, but generally strikes north of east and dips $15-30^{\circ}E.$ Grain trends $N.30-45^{\circ}W.$, dipping $N.80^{\circ}$.

In about the middle of the upper (working) level a small fault striking $N.60^{\circ}W.$ and dipping $35^{\circ}S.$ is seen. The displacement of this fault nowhere exceeds 3 inches, and it would scarcely be noticeable, did it not cut a "loose ribbon" or calcareous bed. When the slate is stripped from this, it is seen to project northward above the fault plane. The fault trace can be seen on the wall overhanging the lower level on its east side, but the displacement rapidly declines so

that the fault is finally lost to view. A feature in the jointing in this quarry is the large number of joints striking northwest.

The Alpha and Acme quarries were both opened prior to 1885; quarrying was temporarily discontinued in that year. Quarrying was actively resumed in 1917 and continued to the present. The products are structural slate, blackboards, roofing material, and especially electrical slate.

13. *Alpha Quarry.* This L-shaped quarry lies due north within 200 feet of the northwesterly edge of the Acme quarry. It measures about 200 feet in both directions.

Operations uncovered the Albion "run," of which the Gray bed appears near the middle of the southwest side, where a shoulder of the wall projects into the quarry; even the Hard Front big bed was found. The beds exposed strike $N.58^{\circ}E.$ and dip $NW.65^{\circ}$; the dip decreasing with depth. The cleavage attitude resembles that of the Acme.

The Alpha quarry was worked before 1885. It has been abandoned for several years, but in 1926 it had been drained and was producing slate.

14. This is a very small trench showing only a thin glacial overburden and a few slate chips. Nothing is known as to the rock underground at this locality.

15. About 600 feet east of the Acme quarry and separated from it by a patch of woods is a small, almost rectangular opening, measuring about 100 by 200 feet. The maximum depth is 70 feet.

This opening shows about 5 feet of overburden along the north side; it consists of clay, slate chips, and occasional boulders. The beds exposed at the surface are in the lower part of the Albion "run." Though poorly shown, they strike $N.60-65^{\circ}E.$, and dip $75^{\circ}NW.$ The cleavage could not be measured but dips gently south. Grain trends $N.40^{\circ}W.$ and is vertical.

This quarry was opened in 1913 and operated for three years, then abandoned.

16. *Albion Superior Quarry.* This opening is 2000 feet east of Alpha. It is a nearly rectangular hole, about 200 feet by 350 feet in area and filled with water. The depth is reputed to be 125 feet.

The overburden attains a maximum thickness of 15 feet. Beneath it a small amount of slate is exposed. Though no beds are recognizable with certainty, it is believed that this opening should show the Albion "run" from end to end at the surface and perhaps even extend a short distance into higher beds; this hypothesis is in agreement with the opinions of the quarrymen. In the one exposure where observable, the strike and dip were $N.61^{\circ}E.$, $76^{\circ}NW.$ Cleavage and grain were not measured.

Quarrying was begun here in 1912 and ceased in 1917. In 1924 reopening was contemplated by a producer.

17. *Stoddard Quarry.* This opening is half a mile east of Alpha and 400 feet east of the Albion Superior. It is about 300 by 200 feet in plan and filled with water.

The 14-foot overburden is the conspicuous feature at this quarry.

Taken in conjunction with a similar eastward thickening of overburden in the Albion Superior opening, this suggests a pre-glacial stream valley not far east of the Stoddard quarry.

On the northeast side of the quarry a small exposure of slate shows a bed about 9 feet "long" measured along the cleavage, with thinner beds on either side. This may well be the outcrop of the Genuine big bed of the Albion "run," which should be exposed here. The stratification strikes $N.51^{\circ}E.$, and dips $85^{\circ}S.$ The cleavage dips gently south. The grain trends $N.44^{\circ}W.$, dipping $60^{\circ}W.$

The opening was made in 1917, but little was removed except the glacial cover. On the whole, this should represent a favorable location for operating, except in that, as depth is reached, the beds will probably dip more gently, "running fast toward the mountain," as the quarrymen put it.

East of this opening about 300 feet lies a small quarry not examined. It was described by a competent operator as having entered the Albion "run."

18. *Dick Quarry.* This small opening lies 1,200 feet $N.70^{\circ}E.$ from the Grand Central quarry, hidden in woods west of the Delaware, Lackawanna & Western Railroad. It measures 50 feet square and is probably not over 35 feet deep, but now filled with water.

Only a small area of slate, with poorly defined bedding, shows above the water. The strike is $N.50^{\circ}E.$, and the dip about $8^{\circ}SE.$ The slate exposed was apparently in the upper part of the Bangor beds.

This prospect was dug in 1900.

19. *Martin and Harding Quarry.* About 500 feet east of the Grand Central quarry is an elongated opening measuring 250 by 100 feet. Its depth to water is 20 feet, but the depth below water level must have been 100 feet.

The beds exposed are said to be part of the Old Bangor "run." They are thin, but cleavage is well developed. At the southern end they strike $N.50^{\circ}E.$ and dip $62^{\circ}SE.$ whereas at the north end, the dip is $45^{\circ}S.$ The quarry is thus on the north limb of an anticline, the axial plane of which dips south. The cleavage strikes $N.80^{\circ}E.$, and dips $20^{\circ}S.$ The grain is parallel with the sides of the quarry, trending $N.40^{\circ}W.$, and stands vertical.

This quarry was opened in 1910 and abandoned in 1912 because of the reduced "length" of the beds, the cleavage and bedding planes intersecting at a high angle, and the beds probably being thinned considerably by tight folding. The product was mainly roofing slate.

20. *Doney's Old Quarry.* This small opening lies 200 feet south of the last. Its maximum depth is probably 75 feet, but water conceals the bottom.

It is said that the 9-foot big bed of the Old Bangor "run" was quarried here. One bed near the south end is 3.5 feet thick. The strike is about $N.60^{\circ}E.$, and the dip approximately $60^{\circ}S.$ The quarry is thus on the same structure as described for the Martin and Harding quarry. The cleavage strikes $N.60^{\circ}E.$, and dips about $10^{\circ}S.$ Grain trends $N.40^{\circ}W.$

Some good blocks of slate are on the dump. The beds seem to be thin, however.

Quarrying was begun here in 1908 and ended in 1910. The product was chiefly roofing slate.

21. *Grand Central Quarry.* This large opening lies along the Delaware, Lackawanna & Western Railroad, about three miles south of the station at Pen Argyl, in the valley of Little Bushkill Creek. The main part of the opening is rectangular, measuring about 250 feet square, with minor irregularities.

The maximum depth attained in quarrying is 175 feet.

As the slate is now nowhere accessible to detailed measurements, the statements of the quarrymen regarding the beds worked were accepted. Mr. M. J. Spry of Bangor reports that the small northward projection from the main quarry entered the Old Bangor "run" and that the main opening is in the Grand Central "run," in which are two big beds, the upper 4 and the lower 8 feet thick, separated by a thickness of 25 feet of smaller beds.

At the surface in the east corner the beds strike $N.75^{\circ}E.$ and dip $25^{\circ}N.$ The dip is said to have changed sharply, however: at a depth of 150 feet or so the dip is south; immediately lower down the direction of dip was once more reversed and the strata inclined to the north. This sharp double reversal in dip was accompanied by the opening of cracks and clefts and by the development of irregular cleavage. The openings formed were heavily filled with quartz and calcite, very deleterious to the slate. When this structure is compared with that in the Martin and Harding and Doney's Old quarries to the west, it is seen that the latter must be on the upper limb of a northward overturned syncline with almost horizontal axial plane; the lower limb of this structure is represented by the north dipping beds at the surface in the Grand Central quarry. The latter, being topographically lower, represents a stratigraphically somewhat lower horizon. These relations are shown in Figure 62.

The cleavage strikes $N.60^{\circ}E.$, and dips $25^{\circ}S.$ The grain, which parallels the southwest edge of the quarry, strikes $N.43^{\circ}W.$

This quarry was opened by R. M. Jones, the "founder of Bangor," about 1880. After many interruptions, usually accompanied by change of ownership, work was stopped about 1916. The production was roofing slate and mill-stock. In the upper part of the quarry, above the point at which the strata turn and dip south, good blackboard slate was obtained. For a time slate was also cut into tiles to be attached to tar paper in the product called "inlaid slate."

22. *Small Grand Central Quarry.* This small opening, measuring 30 by 70 feet, lies about 300 feet due southeast of the large Grand Central quarry. It is a shallow hole containing much waste.

The strata here are in the lower part of the Grand Central "run" but no beds could be definitely correlated with the known sequence. They are probably continuous with those in the northeast wall of the Grand Central. One conspicuous bed has a thickness of 2.5 feet. The strike in this opening is $N.85^{\circ}W.$, and the dip is $11^{\circ}NE.$ Cleavage strikes $N.85^{\circ}E.$ and dips $32^{\circ}SE.$

This small hole was worked in 1905. It is a part of the same property as the larger Bangor Central quarry.

23. A small prospect hole, of irregular shape, lies in a field south

of the road, 1,600 feet S.65°E. from the Grand Central quarry. It is 50 feet on the side and 10 feet deep.

The slate appears to be of fair quality, but no thick beds are seen. The strike is N.60°E., and the dip 10°NW.; the cleavage dips 12°SE., and strikes parallel with the beds. This is merely a prospect.

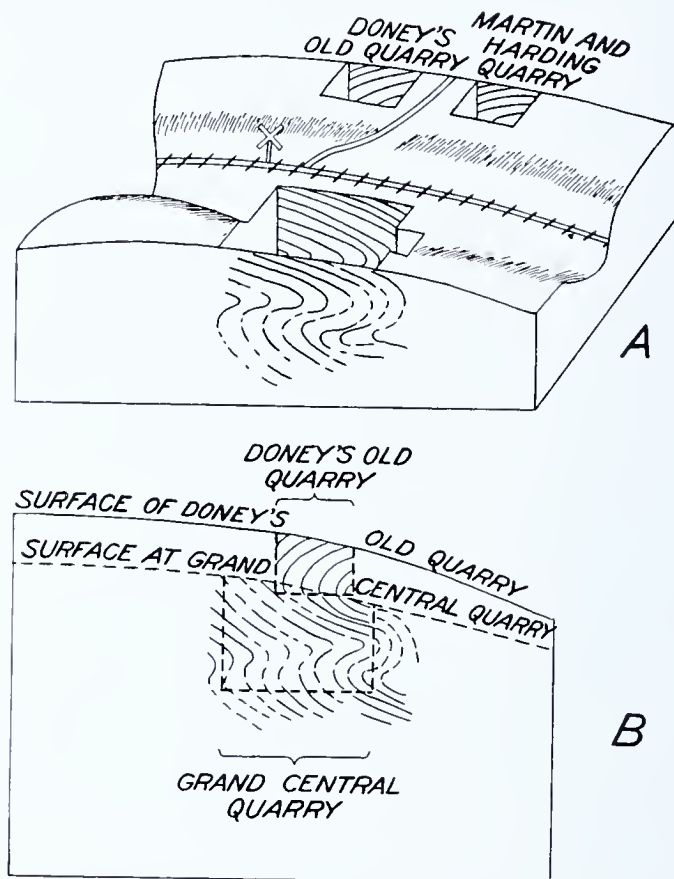


Fig. 62. A. Block diagram to show relations of quarries at Grand Central; view westward from the Grand Central quarry; B. Projection of Doney's Old quarry upon plane of grain in Grand Central quarry, to show true structure.

24. *Doney Quarry.* About 400 feet south of the highway between Wind Gap and Pen Argyl, and three-quarters of a mile east of Alpha is the Doney quarry, an opening 300 by 125 feet in size and 150 feet deep.

The quarry is opened in the lower part of the Albion "run," the Gray bed appearing on the lowest working level and just within the northwest quarry wall at the surface.

On top the beds strike N.68°E., and dip 71°S., but the dip decreases southward, for it is 71° on the north and 68° on the south edge of the opening. As depth is gained the dip increases to 75° on the upper level and even 81°S. on the lower level. The structure is thus the upper (southern) limb of a syncline with axial plane dipping south. Structurally this is in harmony with the New Diamond, Parsons, and Albion Vein quarries.

The cleavage strikes N.75-85°E., and dips 15-18°S. Grain trends N.50°W., and dips vertically. Three definite systems of jointing are recognizable. One strikes N.55-60°W., and dips 32-40°S.; these joints commonly stop at "loose ribbons." A second set strikes N.80°W., with highly varied dips. A third set strikes N.55°E., with dips ranging from 80°S. to 80°N. Not uncommonly these joints unite by an increase in dip of the lower joint.

This quarry was opened in 1919. Operations are progressing under a long-time lease and have been continuous to recent date. The products are blackboards, electrical slate, structural slate, and roofing slate.

25. *New Diamond Quarry.* This opening lies about one thousand feet northeast of the Doney quarry. It is 125 feet wide and 450 feet long. Its greatest depth, attained in the western part, is flooded, the water standing at least 200 feet below the surface.

The beds exposed are a part of the Diamond "run." They cover most of the sequence from the lowest beds seen in the south wall of the New Diamond quarry. On the lowest level two thick beds, the Genuine big bed of the Diamond "run" and the Red bed, measure respectively 78 and 109 inches along the cleavage. At the northern edge of the stripped surface is another thick bed. It is said that these beds are more "tender" or brittle than those of the Albion "run" and hence slightly more difficult to quarry. They are also generally somewhat coarser and less uniform in the size of the grains as seen under the microscope.

At the surface the beds strike N.61°E. and dip 63°S., the dip increasing slightly to the north. The dip also steepens downward, being 63°, 65°, and 70° respectively at depths of 15, 50, and 90 feet below the surface. It is apparent that this quarry is located on the same structure as the Doney quarry, the south limb of a syncline, the axial plane of which dips south.

The cleavage strikes approximately parallel with the beds and dips 12-18°S. The grain trends N.50-58°W., and is vertical or dips steeply east. Although not as clearly falling into systems, there is yet a strong suggestion of the heavy development of northwest-striking joints similar to those in the Doney quarry (see above). The tendency of joints to merge with each other and with "loose ribbons" is a conspicuous feature in this quarry. Thus, a calcareous "ribbon," bordered by an open crevice and highly striated, is seen about midway on the floor of the lowest working level and against it many joints stop abruptly.

This quarry was worked from 1885 until 1900, then lay idle for ten years. Since 1910 it has been in continuous operation. The products are blackboards, electrical slate, and structural material. Roofing slate is not made.

26. *Parsons Quarry.* The Parsons quarry is about a quarter of a mile south of the Delaware, Lackawanna & Western R. R. station at Pen Argyl. It is approximately rectangular in ground plan, measuring about 350 by 175 feet. Work is conducted on several levels, the lowest of which was 725 feet below the surface in 1931—probably the deepest quarry in the United States (see Plate 49, B.)

The "back" of the quarry lies along a "loose ribbon." The beds exposed between this and the "front" of the quarry consist of some

of those seen in the New Diamond quarry and of other beds lying higher in the sequence and reputed to have been found in the old Diamond quarry.

At the surface the strike of bedding is N.57-61°E., and the dip about 63°S. Lower, on the 380-foot "piece," the beds dip as much as 87°S. At the greatest depth the dip is reversed and the beds incline northward 57°. The structure is thus the same as that of the New Diamond quarry, but the greater depth has carried the work below the synclinal axis. In the upper level the Red bed, the Genuine big bed (Diamond "run"), and the Johnny Knack bed are especially thick and valuable.

The cleavage varies somewhat in strike, readings having been obtained between the limits N.71°E. and N.84°W.; the dips are low, averaging 10 to 12°S. Grain trends N.45-50°W., and is vertical or inclines steeply eastward.

Jointing was studied with care wherever accessible. At the surface a long, conspicuous joint is seen in the northwest wall. Below this a series of joints, striking northeast and apparently dipping about 60°S., begins and continues downward. Above the one conspicuous joint mentioned is another system dipping northwest. The deeper parts of the quarry showed almost no jointing, but the highest working level exhibits two systems, one suggesting in its strike the N.75°W. joints of the Doney quarry, the other trending approximately N.50°E.

The quarry was opened in 1892 and has been operated continuously.

The products of the Parsons Brothers Slate Company include roofing slate, structural material, electrical slate, grave vaults, blackboards, slate granules, and slate powder.

The company operates a slate pulverizing and grinding mill, described by Bowles.¹

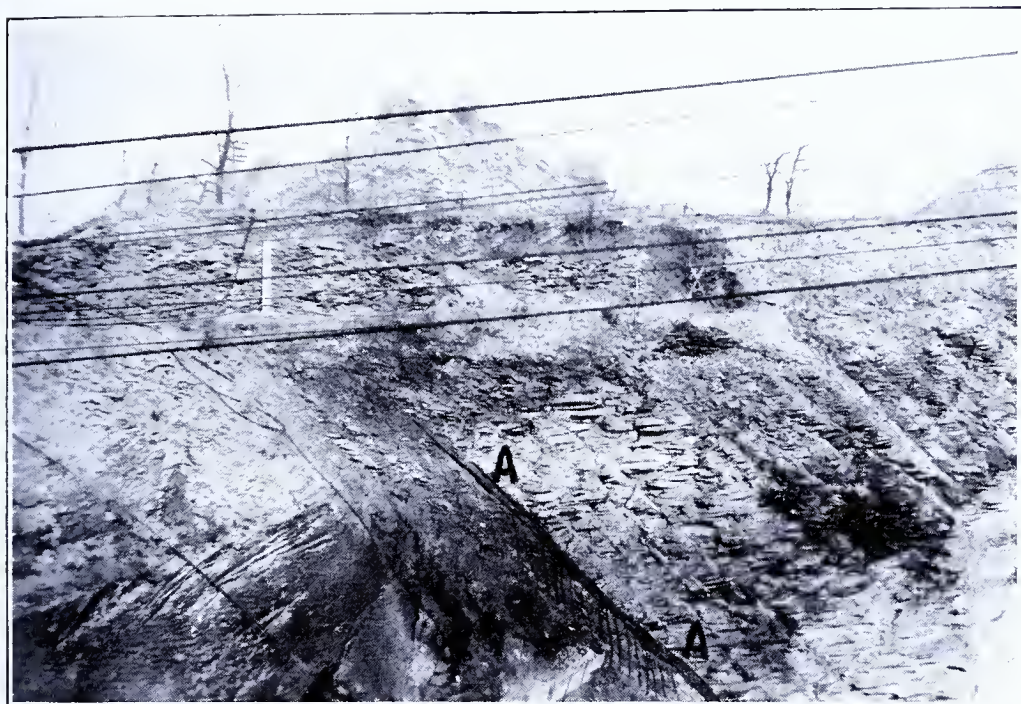
27. Albion Vein Quarry. The Albion Vein (West Albion or Stoddard) quarry lies 300 feet south of the Parsons quarry and south of the Delaware, Lackawanna & Western Railroad. In general plan it is quadrangular, measuring 400 by 500 feet. This old opening, now abandoned, is the second deepest in the region, being exceeded only by the Parsons quarry, and attaining a maximum depth of 500 feet. A new hole along the southeast side of the one just described was opened in 1924 and by 1930 had attained a depth of 150 feet.

Structurally the old quarry was situated similarly to the Parsons quarry, but in beds lower in the sequence. The Albion "run" has been opened, almost from top to bottom. The "loose ribbon" making up the northwest wall is said to be in the Jenny Weeks bed, and the Front big bed, which is the southmost or lowest stratum in the Albion "run", lies just south of the southeast quarry wall; about 40 feet north of the east corner, the Gray bed comes to the surface. The new opening is in beds just south of the Gray bed.

At the surface the beds strike N.60°E., and dip 37-44°S., but as they descend a vertical attitude is acquired at a depth of about 250 feet. Below this point the beds dip north, to a depth of 350 feet beneath the surface, where the vertical is resumed for a short distance. Then the dip is north, vertical, and southward again, but very steep, and at the top of the working level a steep southward dip (85°) is seen. At the

¹ Op. cit., p. 114.

PLATE 51.



A. Bedding slip fault or "loose ribbon" in north corner of Albion Vein quarry; fault plane at A; typical closely spaced vertical joints below it.



B. Bedding slip fault of West Bangor quarry, as seen in the north-east wall; fault plane is to left of A; beds south (to right) of fault dip steeply south at surface; north of fault the dip is more gentle and north; note joints on smooth face north of fault.

lowest point, however, the dip is clearly 46°N . The cleavage strikes $\text{N.}60\text{--}70^{\circ}\text{E.}$, and dips $13\text{--}20^{\circ}\text{S}$. Grain trends $\text{N.}52^{\circ}\text{W}$.

Two rather unusual structural features were to be seen in the old opening. The "back" (northwest) wall appears to be formed by a bedding plane. Close inspection, however, shows this to be a bedding-slip fault of the type already described (see p. 166). South of the fault plane the beds are thrown into a syncline on a far smaller scale than is formed by the fault plane itself. Against the fault plane the cleavage is curly and mashed, and on the northern side it tends to have a high southward dip as the fault is approached, suggesting drag. Beneath the fault numerous closely spaced, almost vertical joints, partly calcite- and quartz-filled, are seen. The fault gouge is 2-3 feet wide, with quartz and calcite filling. The striae where seen dip almost vertically and extend southward parallel to the bedding dip. Actually there is a zone made of two such fault planes, close together (see Plate 51, A.)

In the north corner of the lowest level of the old opening a fault of a different nature was seen. This strikes $\text{N.}25^{\circ}\text{E.}$ and dips 35°SE . In this case the movement was probably horizontal, the east side moving north, and the displacement was not more than two feet along the plane.

The outstanding feature of jointing in this quarry is its close resemblance to the systems of the Parsons quarry. The regularity in the jointing here favors quarrying, because the removal of the slate in rhombic blocks is permitted. Some of the northwesterly joint surfaces bear pyrite lenses.

The Albion Vein quarry was opened in 1902 and in 1908 passed into the hands of the Albion Vein Slate Company.

The production includes roofing slate, all varieties of mill stock and structural material, and blackboards.

28. Two small quarries lie about 1,400 feet $\text{S.}70^{\circ}\text{E.}$ from the Albion Vein quarry, in the field east of the road that leads past the Albion Vein opening. The larger quarry is 50 by 180 feet and the other is about 40 feet square. Neither can be more than 35 feet deep. The geology of these two openings is the same. In the larger opening the beds are thin; but one of them is about 12 feet thick. Cross-bedding is well developed in the sandy layers, the laminae dipping west. The strata strike $\text{N.}70^{\circ}\text{E.}$, and dip 10°NW . on the southern edge, but dip 85°SW . in the northern side of the opening; the structure is thus a northward overturned anticline. As the cleavage strikes $\text{N.}40^{\circ}\text{E.}$, and dips 10°SE . it is seen that the structure plunges east, a fact further confirmed by the observation that the beds along the axis do actually dip 7° toward the east. The grain trends $\text{N.}40^{\circ}\text{W.}$, and dips 80°E.

Nothing is known of the history of this quarry. It has the appearance of having been abandoned at least 20 years ago.

29. *Albion Quarry.* This large opening is worked by two companies, the Keenan Structural Slate Company, which operates the western half of the quarry, and the Stephens-Jackson Company.

It is 2,000 feet south of the Pen Argyl post office and 1,500 feet east of the Parsons quarry, from which its huge dump can be seen rising to the east. It is the largest opening in the district in area and in vol-

ume. Rhombic in shape, it has areal dimensions of 600 feet N.45°W., and 900 feet N.60°E. Its depth varies, as there are several working levels in each of the two parts, but the greatest depth measured is 325 feet below the surface, the depth of the water level in the bottom of the pit.

On the east side the Stephens-Jackson Company is operating on several levels, each level nearer the middle of the opening than that above. Along the west side the Keenan Company has several similarly step-like levels. -

The geology of both parts of the opening can best be described at once. The beds exposed are all in the Albion "run". The Jenny Weeks bed is seen in the northernmost reentrant in the northwest wall of the pit. The Genuine big bed of the Albion "run" is quarried on several levels in the east part of the opening. The Gray bed comes to the surface about the middle of the northeast and southwest walls.

Operations in the Keenan half of the quarry have been confined in recent years to the upper beds of the Albion "run", from the Gray bed on; in the Stephens-Jackson half the levels have developed chiefly the middle and lower parts of the Albion "run", although the lower working levels extend almost to the Jenny Weeks bed.

When the northeast wall is viewed from the southwest side of the quarry, the true structure is readily seen. It is evident that the beds dip south at the surface, become vertical at the depth of about 200 feet, and then turn so as to dip north. There is thus defined a syncline having an axial plane that inclines gently southward (see Plate 49, A, and Figure 52.) This structure carries on into the southwest wall of the opening. The beds are generally thicker on the lower limb of the syncline than on the upper.

Near the middle of the northwest wall, just west of the property line, a reentrant leads north. The north wall of this step-like reentrant is a very smooth surface, apparently a bedding plane. This smooth surface forms the upper half of the wall; lower down, however, it is broken away, partly by channelling, partly by undercutting. This surface is a bedding slip fault, and has been described under that head on page 166.

An interesting fact in regard to the cleavage in this quarry is its curvature. In the upper levels of the east half of the opening the cleavage locally actually dips north, yet is not crumpled. The impression of a very gentle arch is conveyed by this departure from the customary southward dip. Elsewhere the cleavage dips gently south. The grain in the west half of the quarry strikes N.45-55°W., and is vertical. In the east half it swings more northerly, N.38°W., being recorded.

Joint systems are recognized with difficulty. A set of steeply dipping joints strikes N.35°E. in the western part of the hole, and their counterparts dipping more gently (70°) north are recognizable in the Stephens-Jackson part of the opening. Higher up, joints in the east part of the quarry strike N.60-75°E., and dip moderately or gently north. The regularity of the joints in these upper levels is striking (see Plate 10, A).

In this opening formerly called the Courtney quarry, work has continued for 60 years. The production of both operating companies in-

cludes all varieties of structural slate, blackboards, electrical slate, and roofing.

30. *Jackson Bangor No. 7 Quarry.* Southeast of the main part of the town of Pen Argyl are seven openings which have long been known as the Jackson Bangor quarries; older names for this group of openings still persist, however, and some of them are used in this report. The seven quarries are generally referred to by number, the old Pennsylvania quarry, that farthest northeast of the group, being sometimes spoken of as the Jackson Bangor No. 1.

The southwesternmost quarry is designated by the owners the Jackson Bangor No. 7 quarry. It lies about 1,000 feet east of the Albion quarry and measures 250 by 300 feet. At the time of these studies the east side of the quarry was being stripped for further development, but the main hole is flooded to a depth of about 150 feet.

The quarry was not studied in detail because of its inaccessibility. The overburden of glacial till is 20 to 35 feet thick.

The quarry at the surface is opened near the middle of the Albion "run". Approximately midway in the northeast side the Gray bed comes to the surface. The opening also yielded the Little Hard big and Genuine big beds.

The strata strike N.63°E. and dip 46°SE. at the surface. At the depth of about 160 feet the strata are said to have been cut by a fault that is probably the one seen in the lowest level of the Jackson Bangor No. 6 quarry. Below this fault the beds moved northward, according to one observer, the Little Hard big bed above against the Genuine big bed below, a movement of about 70 feet along the fault plane in the direction N.30°W. The estimates of the amount of displacement vary greatly, however, for one quarryman says that the movement equalled the entire thickness of the Albion "run". As in the quarries to the east and west, the beds turn at some depth, so as to dip northwest in the lower depths of the quarry. The cleavage strikes N.42°E., and dips 16°SE. Grain trends N.47°W. A well developed set of joints is seen on the walls; these strike N.20-30°E. and dip 30°NW.

31. *United States (Jackson Bangor No. 3) Quarry.* This quarry lies about 1,000 feet S.60°E. from the Pen Argyl post office. It is of irregular shape, but roughly 1200 feet by 300 feet, maximum dimensions. It was largely filled with water when visited in 1924, and the water covers all but the upper 50 feet of slate. On the southwest side, however, extensive stripping was in progress, and the hole was being enlarged beyond the dimensions shown on the maps and given above.

As the slate is not accessible at depth, only surface observations could here be made. The opening has given its name to a series of beds which were not accessible to measurement in any of the quarries, the United States "run".

A study of the structure indicates that the beds in general dip southeast on the south (upper) limb of a northward overturned syncline. In the northwest part of the quarry the dip is 50° NW. In the middle of the west part the strike is N.50-65°E., the dips varying between 60 and 80°SE., steepening southward. Erosion in this part of the structure must have removed a sharp turn, however, and a slight eastward pitch, for on the extreme east edge of the opening the beds are nearly horizontal, changing from a dip of 24°SE., at the northeast

corner to 37°NW. , at the southeast corner, the strike remaining $\text{N.}63\text{--}66^{\circ}\text{E.}$ It is quite possible that this marked difference in structure may be due to a fault that cuts across the quarry. If so, the fault is probably the higher one of the two in the Jackson Bangor No. 6 quarry, for the projection of its plane would give it that position. As the movement of the eastern block of this fault was down and southward in the Jackson Bangor No. 6 opening, it is altogether probable that the appearance of a gentle syncline in the strata on the east side of the United States quarry is due to the dropping of the upper limb of a syncline below the erosion surface at this point. Quarrymen commonly speak of a fault in this quarry and it is believed that this is the fault referred to.

The cleavage strikes uniformly about $\text{N.}70\text{--}75^{\circ}\text{E.}$, and dips $40\text{--}50^{\circ}\text{SE.}$ Grain trends $\text{N.}47^{\circ}\text{W.}$ The few joints accessible strike $\text{N.}30^{\circ}\text{E.}$ with dips of 80°NW. , or $\text{N.}20^{\circ}\text{W.}$, dipping 58°N.

This is one of the oldest quarries of the district. Its early history is not known, but in 1907 the property was purchased by the Jackson Bangor Slate Company. Since the World War it has not been worked, but in 1925 it was being opened on the west side.

32. *Hercules Quarry.* Various names have been applied to this opening, including Masters, Bolger, and Jackson Bangor N. 2 quarry. The old name Hercules quarry is here retained. This opening is only 100 feet north of the United States quarry. It measures 400 by 200 feet and is worked on one level only, the bottom of the quarry, at a depth of 250 feet.

The beds exposed make up the Pennsylvania "run", a series that derives its name from the quarry to the east. As far as known, these strata are not opened in other quarries of the region. One conspicuous bed, having a thickness of 11 feet, 3 inches, is seen in the present working level near the north wall.

At the surface the bedding strikes $\text{N.}47^{\circ}\text{E.}$, and dips 31°N. , along the north wall of the quarry and 39° on the south wall. At a depth of 80 feet the dip is vertical, hence marks the almost horizontal axis of the northward overturned anticline. There are several smaller rolls, to a depth of about 150 feet; then the beds resume the northward dip, which they retain to the bottom of the quarry. There is evidence in the lowest part of the wall, however, that the beds again assume a steeper dip, suggesting the occurrence of another axis with depth (see Figure 63).

Several smaller faults are visible in the northwest wall, the bedding traces being offset as they cross the fault planes. In the bottom of the opening there is a small fault, the strike and dip of which are $\text{N.}5\text{--}20^{\circ}\text{W.}$, $38\text{--}50^{\circ}\text{NE.}$, respectively. The displacement is about 7 feet in a $\text{N.}50^{\circ}\text{W.}$ direction along the fault plane. Striae on the fault wall dip 25°SE. in the plane of the fault; the movement was thus largely horizontal, the east side moving northward. This probably represents a minor adjustment of a thrust nature, giving the same effect as the faults already mentioned in the Albion Vein and the Jackson Bangor No. 7 quarries, and yet to be described in the Jackson Bangor No. 6 quarry (see below). Projected to the surface, the fault plane appears to coincide most closely with the fault of the Jackson Bangor No. 6, but as the movements in these two faults are oppositely directed,

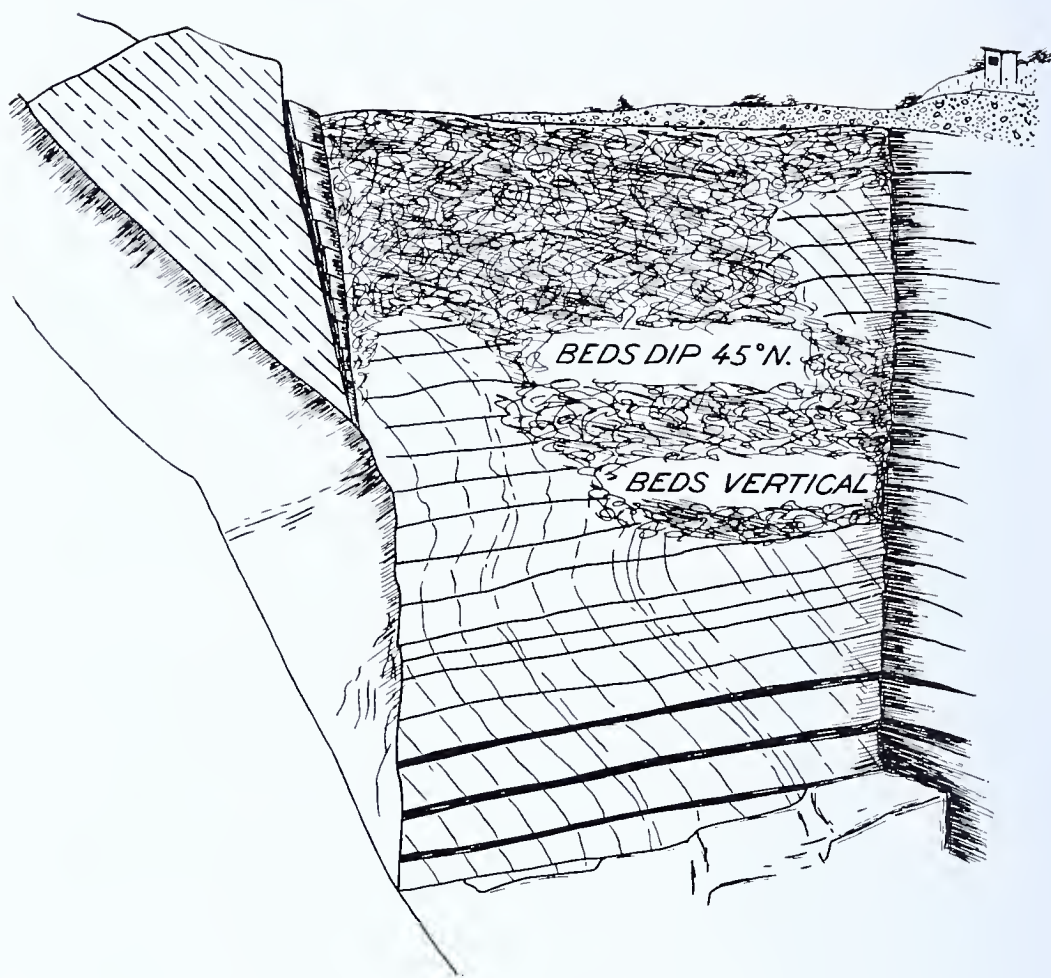


Fig. 63. Southwest wall of Hercules quarry, from east corner. Anticlinal axes at depth of 80 and 200 feet. Some foreshortening in deeper parts of quarry.

it is incorrect to correlate the two. The Hercules fault is of too small a displacement to be shown on the maps.

Cleavage strikes $N.43^{\circ}E.$, and dips $24^{\circ}SE.$ at the surface. On the working level the strike is $N.65-90^{\circ}E.$, and the dips are slightly lower. Grain trends $N.50-60^{\circ}W.$ The joints measured all fall into a $N.60^{\circ}E.$ system, much like one of the sets observed in the Albion Vein and Jackson Bangor No. 6 quarries.

This quarry was opened about 1885 and long worked by the Hercules Slate Company, and has been worked recently by the Belmont Slate Company. The products include roofing slate, blackboards, slate for plumbing fixtures, grave vaults, table tops, and other structural material, and electrical slate.

33. Pennsylvania Quarry. In ground plan this is a rhombic opening lying about 500 feet $N.30^{\circ}E.$ from the Hercules quarry. It measures 300 feet along each side.

Even as early as in 1833 the quarry was "full of water".¹ Today

¹ Sanders, R. H., *Geology of Lehigh and Northampton Counties: Pennsylvania Second Geol. Survey, D. 3, vol. I, p. 97, 1883.*

the opening shows about 30 feet of slate above the level of the water. The probable total depth is 150 feet.

The beds opened are probably slightly higher in the sequence than those in the Hercules quarry. One conspicuous bed, estimated to be 10 feet thick, occurs about midway in the northwest wall. The beds strike N.55°E., and dip 62°N. at the northwest edge, 22°N. at the southeast edge. North of this quarry, therefore, an anticlinal axis should emerge. Cleavage strikes N.62°E., dips 22°S.; grain strikes N.55°W. and is vertical.

Since 1885 this quarry has experienced repeated revivals of operation but apparently none of long duration. It was the first quarry opened in the Jackson Bangor properties, and is therefore sometimes spoken of as the Jackson Bangor No. 1 quarry. The products were roofing slate, blackboard material, and structural slate.

34. Diamond Quarry. This quarry lies about 200 feet south of the middle of the United States quarry. It measures about 300 feet on each side and, though now flooded, is at least 175 feet deep.

The beds exposed constitute the Diamond "run" and are seen again in the Parsons and New Diamond quarries. In the Diamond quarry they were not studied in detail because not accessible. The structure is uniform everywhere in the quarry, the strike and dip of three observations averaging N.67°E., 69°SE. The cleavage strike varies greatly, but apparently the mean is about N.40°E., with gentle south dips. The grain trends N.53-63°W.

The northwest ("back") wall is developed along a "loose ribbon". This bears numerous joints two feet apart or less and appearing to strike N.15-35°E., and to dip 50°S.; they are quartz- and calcite-filled. In the southeast corner several joints strike N.5°W., and dip 50°SW.

It is said that the water level of this quarry is related to that of the Jackson Bangor No. 5 (see below). When No. 5 is drained, the level in the Diamond quarry is noticeably low.

Like the Pennsylvania quarry, this opening has been abandoned for several years. It is sometimes called the Jackson Bangor No. 4 quarry.

35. Jackson Bangor No. 6 Quarry. This deep opening lies about 1,200 feet S.50°E. from the Pen Argyll post office, and is the next quarry due east of the Jackson Bangor No. 7 opening. At the surface it is 250 by 300 feet. The depth was 380 feet in the lowest level (1924), but continued sinking since has increased that figure. Upper levels rise as benches along the northeast side of the quarry.

This quarry on its several working levels opens all of the Albion "run". On the south edge of the lowest level is the Hard Front big bed. On the uppermost level the lower part of the Jenny Weeks bed is seen against the north wall.

Structurally the quarry exposes a rather open syncline with an almost flat axial plane, the two upper levels being in the upper (south) limb and the lowest piece in the north limb. Thus, on the topmost level the beds strike N.60-65°E., and dip 65-80°E., while in the lowest level they strike N.40-50°E., and dip 10-35°NW. The strikes on the upper and lower limbs diverge, as noted, and the cleavage strike is more nearly parallel with the strike of the beds below than above. There is a suggestion in these relations that the axial line of the beds

swings north as it is followed east. The cleavage dips gently south, $15-30^{\circ}$ and strikes $N.40-60^{\circ}E$. Grain trends $N.45^{\circ}W$. Jointing is not distinctive.

Three faults are seen in this quarry. They all strike northwest and dip to the northeast, and there is evidence that the movement is mainly horizontal and southward on the east side of the fault plane. One is seen in two of the quarry walls near the east corner of the opening, about 50 feet below the surface. The other two are on the lowest working level. For a further description of these faults, the reader is referred to pages 164-165. Offsets of a similar nature, but on a much smaller scale, are visible on the northwest and southwest walls.

Beginning at the surface, along the northeast wall of the quarry, a conspicuous "loose ribbon" leads downward in a curve parallel with the bedding. Although there apparently has not been much movement along the plane at this point, it is believed that the open crevice or "loose ribbon" represents the trace of a bedding slip fault.

In quarrying, the management has found operations very expensive at certain stages in the descent, because of numerous closely spaced joints attributed to the three high angle faults mentioned. Although it is true that some jointing is associated with these faults, it is almost certain that most of the observed joints are related to the movement along the bedding slip fault, a structure which, being almost parallel with the bedding, is readily overlooked. On the whole, it is probable that this quarry will be more, rather than less profitable as depth is gained, as this increase in depth gives to the working level a greater horizontal distance from the bedding slip, the latter receding farther and farther into the wall.

This opening was worked by the Jackson Slate Company previous to its purchase in 1907 by the Jackson Bangor Company. The date of opening is not known to the writer. The yield includes all kinds of slate products.

36. *Jackson Bangor No. 6 Small Quarry.* This small opening lies immediately southeast of the main opening of the Jackson Bangor No. 6. It is about 75 feet square and 105 feet deep. In the northeast corner the Gray bed is exposed. The structure resembles that of the main opening. At the surface the strata dip $48^{\circ}SE$., but in the bottom the dip is $75^{\circ}SE$., and is plainly steepening. The extent of the horizontal shift involved in the fault described as visible in the southeast corner of the No. 6 quarry is indicated by the southward shift of the Gray bed from its outcrop at the middle of the main No. 6 quarry to the northeast corner of this small opening, a displacement, as measured along the horizontal reference surface, of about 125 feet.

37. *Jackson Bangor No. 5 (Valley) Quarry.* This quarry is at the southeast edge of Pen Argyl, on the Bangor & Portland (Delaware, Lackawanna & Western) R. R. It is one of the larger openings of the Pen Argyl group, measuring 500 by 250 feet.

Development is in several levels, the main or bottom one varying in depth up to 225 feet.

There is a heavy overburden of 30 feet of rounded, unstriated boulders, set in sandy clay. Beneath this, near the middle of the northeast wall, the Gray bed is plainly seen and shows again in the

bottom of the quarry. The entire Albion "run" is thus exposed in the workings, although the divergence between the strike of the beds and the longer dimension of the opening carries the Gray and lower beds into the southeast wall. The structure is that of a northward overturned anticline above and its complementary syncline below: the beds at the surface dip 44°NW. ; but lower down they dip southeast at moderate angles; at still greater depths the dip is north again, from 50 to 80° . The strikes vary slightly, but the average is about $\text{N.}70^{\circ}\text{E.}$ Cleavage strikes $\text{N.}80^{\circ}\text{E.}$, and dips $15\text{--}30^{\circ}\text{W.}$ Grain trends $\text{N.}45\text{--}53^{\circ}\text{W.}$

It is difficult to speak of any of the joints as falling into distinct systems; almost all strike northeast, and of these many strike $\text{N.}50^{\circ}\text{E.}$, whereas another group strikes about due east; both have vertical dips.

Near the northeast corner a fault is visible on the wall. The trace of the fault plane dips north, which suggests a northwest strike with a northeast dip, similar to the faults already described in the quarries to the west. Unfortunately, however, the fault plane was not accessible and its actual strike and dip, as well as the amount of movement, could not be measured. The beds east of the fault, however, are said to have moved north. Small faults with similar movements are seen near the surface in the northeast wall just north of the east corner.

The quarry was opened long ago. In 1907 the property was purchased by the Jackson Bangor Slate Company, the present operators. In 1908, the No. 6 and the No. 7 quarries produced together 75,000 squares of roofing slate, but production declined greatly during the war and has but lately resumed normal size. A recent innovation is an excellently equipped roofing slate mill¹. The production includes roofing slate, blackboards, electrical slate, and slate for structural purposes. The company makes a specialty of the latter material shaped to meet particular needs.

38. About 600 feet due east of the Jackson Bangor No. 5 quarry is an old pit, long deserted. It measures about 100 by 200 feet, and is only 20 feet deep.

The strata could not be correlated with any of the measured sections, but are evidently well below the Albion "run". They strike $\text{N.}75^{\circ}\text{E.}$, and dip 16°S. , apparently on the south (upper) limb of a syncline with horizontal axial plane. The cleavage strikes $\text{N.}58^{\circ}\text{E.}$, dipping $3\text{--}5^{\circ}\text{N.}$ The grain trends $\text{N.}35^{\circ}\text{W.}$

This quarrying was done more than 20 years ago and was abandoned when it was found to enter beds below the Albion "run".

39. Another old pit lies about 1,800 feet $\text{N.}80^{\circ}\text{E.}$ from the Diamond quarry. It is now filled with water, and is only about 130 by 75 feet in size.

The beds are said to be of the Albion "run". They strike $\text{N.}62^{\circ}\text{E.}$, and dip 23°S. The dip thus resembles in direction that in Quarry No. 38, but is steeper, probably because the axial plane of the fold dips southward. In the northwest corner the cleavage strikes $\text{N.}25^{\circ}\text{E.}$, and dips 8°N. at the one locality where the strike was observed. Grain trend is $\text{N.}40^{\circ}\text{W.}$

40. *Old Crown Quarry.* This quarry lies about 1,500 feet ENE.

¹ Bowles, Oliver, Recent progress in slate technology: U. S. Bur. of Mines, Reports of Investigations, fig. 1, 1926.
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from the Pennsylvania quarry and only about 50 feet north of the Pen Argyl-Bangor highway. It is 140 by 115 feet in size and 20 feet deep to water level, but must have a far greater total depth.

The beds should here be the same as at the Pennsylvania quarry to the west. The strike is N.60°E., with dips of 25°NW. One bed measures 9 feet along the cleavage. The cleavage strikes approximately N.58°E., and dips gently southward. Grain trends N.40°W. The history is given under the description of the Crown quarry.

41. Crown Quarry. About 1,800 feet N.50°E., of the Pen Argyl city park, and in the little settlement of West Bangor, is the new Crown quarry, a rectangular opening 300 by 225 feet in size with a depth of about 110 feet, partly flooded.

Under a light overburden of glacial drift, the slate beds appear striking N.53°E., with a dip of 72°N. at the south end of the quarry, but only 33° at the north end. A synclinal axial plane with a southward dip may be expected to appear at the surface south of this quarry. The beds exposed are continuous along their strike with those in the West Bangor quarry described below.

Cleavage strikes N.53°E., dips 40°S. The grain trends about N.40°W. On account of the heavy weathering of the slate, joints are readily studied from the surface. A bedding slip fault, unquestionably continuous with that seen in the Bangor Fidelity and West Bangor quarries (which see), shows in the northeast quarry wall about 100 feet from the south end, but the slipping described in the easterly quarries is greatly reduced, and it is evident that the faulting is on the wane westward.

Quarrying here was begun in 1892. In 1910 this and the Old Crown quarry to the south came under the management of the Crown Slate Company of Pen Argyl, Pa. The quarry is now not worked. The production included mainly electrical, structural, and blackboard material. Very little roofing slate was made.

42. Bangor Fidelity Quarry. About 600 feet east of the Crown quarry is the western of two almost equal-sized openings, rhombic and about 500 by 225 feet in ground plan; the western (Bangor Fidelity) quarry is about 300 feet deep.

This quarry is so close to the West Bangor that the geology of the two openings is practically identical, and the reader is referred to the description of that opening. History of development, too, is linked with that of the West Bangor quarry and discussed under that head.

43. West Bangor Quarry. A wall, in places only two feet thick, separates this from the quarry to the west.

The slate is somewhat softer and more brittle than that in the Albion "run".

At the surface in the north end of the quarry the beds strike N.57°E., dip 43°N.; in the south end the dip is 65°S. In the quarry wall the dip reverses and in the working level all beds dip north, at angles of 10° to 15°. As in the Bangor Fidelity quarry, therefore, a synclinal axial plane, dipping 14°S., emerges near the middle of the quarry, and an anticlinal axial plane is doubtless present a little south of the opening.

The beds worked include four conspicuously thick ones. Measurements give the following thicknesses, in the order of superposition:

Measured sequence in West Bangor quarry.

| Name | Thickness | | Chief Use |
|---------------------------------------|-----------|-----|------------------|
| | Ft. | In. | |
| Big bed | 3 | 6 | Electrical slate |
| Hard roll | | 6 | |
| Intervening beds with "ribbons" | 90 | 0* | |
| Big bed | 8 | 2 | Blackboard |
| Hard roll | | 3 | |
| Intervening beds with "ribbons" | 10 | 6* | |
| Big bed | 6 | 10 | Various |
| Hard roll | | 4 | |
| Intervening beds with "ribbons" | 90 | 0* | |
| Big bed | 4 | 5 | Blackboard |
| Hard roll | | 23 | |

* Thickness estimated, not accurate.

The cleavage strikes N.61°E., dips 30°S. The grain trends N.45°W., dips 80°E. In the wall of the quarry a set of joints trending N.55°E., and dipping 75°S. is seen. In the bottom a system strikes N.10-30°E., dips 70°S. There is a tendency for the dips of the first set of joints to cut the bedding dip at right angles.

About midway in the quarry sides a bedding slip fault comes to the surface. With it are associated the usual numerous joints gently inclined to the plane of the fault. The beds south of the fault bulge and dip noticeably first south, then north, while those north of the fault are vertical near the plane and dip north farther away; the closer compression of the fold south of the fault plane is thus clearly defined. This bedding slip fault can be traced west through the Bangor Fidelity and Crown quarries; its outcrop at the surface is marked by a shattered zone that weathers so easily as to leave a conspicuous notch in the quarry wall. The feature is shown in Plate 51, B.

The West Bangor quarry was opened in 1887. It was taken over by several firms in succession with occasional periods of idleness. About 1912 operations were resumed and continued until 1919, but the quarry was once more being worked in 1924 by the Bangor Fidelity Company.

The products are structural, electrical, roofing, and backboard slate.

44. *Bangor Superior Quarry, small opening.* A small opening of the Bangor Superior quarry lies just west of the main hole bearing that name. It represents a stripped area practically continuous with the main hole.

45. *Bangor Superior Quarry.* The Bangor Superior quarry is about half a mile due west of Roseto, and about 2,000 feet N.45°E. of the West Bangor quarry. It is roughly 200 feet square. The depth to the present water level is 130 feet.

Three thick beds are worked, one of which is the Johnny Kress bed, having a "length" of 9 feet, 7 inches along the cleavage; this bed, by careful measurements, could be correlated with one of the thick beds in the West Bangor quarry. Stratigraphically about 40 feet beneath it is a bed about 7 feet "long" (measured on the cleavage); roughly 20 feet lower in the sequence is another thick bed about 10 feet "long".

A feature in this quarry is the northwest strike of the beds. Thus,

at the surface the strike and dip are N.62°W., 11°S. In the bottom of the quarry along the south side the strike is N.76°W., the dip 12°S. The strike of the cleavage, however, retains a northeast direction, being N.61°E., with a 35°S. dip at the surface, while in the bottom the relations are the same. It is thus clear that the quarry is on a westward pitching syncline. The grain generally trends N.50° W., dips 75-90°E. A set of joints, striking N.42-50°W., and dipping 60-80°S., is seen in the east corner of the opening.

This quarry was first opened in 1884. The lease on the property changed hands repeatedly, with corresponding pauses in production, but since 1920 the quarry has been continuously operated by the Slate Products Company, Incorporated, of Bangor, Pa. The products include structural and electrical slate and smaller quantities of roofing slate and blackboards.

46. *Keller Quarry.* This small opening is on the northerly slope of the same hill as the American Bangor quarry, and about 1,200 feet due north of that quarry. It is small and only a little slate is seen. The beds strike N.30°E., dip 60°S. Cleavage is horizontal or dips gently north, with a slight tendency to curve. No beds exceeding two feet in thickness are exposed. The strata are said to be part of the North Bangor No. 3 "run".

47. *Stecker Quarry.* The Stecker quarry is a prospect pit, about 35 by 140 feet in ground dimensions, lying 800 feet due north of the American Bangor quarry, and about 12 feet deep.

The bedding strikes N.31°E., and dips 63°S. on the northwest side, but only 33°S. on the southeast. Many "hard rolls" are visible. The opening is thought to have exposed the North Bangor No. 2 "run". The grain trends N.40°W.; cleavage is horizontal.

48. *Uhler Quarry.* The road from Delabole to Bangor passes about 1,000 feet south of the Bangor Southern and American Bangor quarries and then, continuing eastward, crosses one of the headwaters of Martins Creek before rising to the hills southwest of Bangor. Up the valley of this creek and on its west side, approximately 600 feet north of the road, is a small opening (Quarry No. 49) on the property of Mr. Uhler of Bangor. It measures 20 by 40 feet and is 15 feet deep to water.

About 400 feet farther north, on the same side of the stream is another small quarry, here spoken of as one of the Uhler quarries (No. 48). It is about 40 feet square and probably 40 feet deep, but filled with water.

The beds exposed in the north opening are said to be in the North Bangor or North Bangor No. 3 "run," but they could not be identified by the writer. They strike N.70°W., dip 15°N. Cleavage strikes N.80°E., dips gently south. The cleavage is fairly regular, but the slate is closely ribboned.

This and the pit 400 feet south were opened about 1905.

49. *Uhler Quarry.* The location and dimensions and the history of this opening have already been given under the description of Quarry No. 48.

The excavation is said to have laid bare a part of the Old Bangor

“run”. The beds strike due east, dip about 35° N. Those exposed are rather closely ribboned, and overturning is suggested in the northeast corner. It is reported that there was a big fault in this opening, but the rumors are vague and not supported by other evidence.

50. *American Bangor Quarry.* This opening is about midway between the towns of Bangor, Pen Argyl, and Ackermanville, and 1.5 miles from each. Its high dump, on which one mast stands, like a flag staff above a ruined fort, is visible from high points several miles distant. The large opening is about 300 feet wide and 500 feet long. The maximum depth to the water that fills the quarry bottom is estimated at 270 feet, but the total depth is reported to have been about 370 feet.

Beneath an overburden 15 feet thick the beds are seen to strike N. $60-70^{\circ}$ E., dip $15-30^{\circ}$ S., the steeper dips being along the south side. It is said by Mr. Blake of Bangor that the strata steepen slightly in the bottom of the quarry. Apparently they are on the upper limb of an overturned syncline having a south dipping axial plane. The structure probably pitches west, so as to carry it below ground level in the Bangor Southern quarry.

The quarry walls are now inaccessible, but operations are said to have exposed the middle of the Old Bangor “run” and the Gray bed was encountered at no great depth. The cleavage strikes approximately N. 70° E., dips 8° S. The grain trends N. 43° W., and is vertical. Vertical joints are prominently developed, striking N. $48-53^{\circ}$ E. Such a joint, apparently continuous, forms the entire northwest quarry wall. The surfaces of joints of this system are commonly quartz or calcite-coated, the quartz being the earlier mineral.

Structurally the beds in this quarry, as far as can be determined, are continuous with those in the southern of the two Uhler quarries to the east. The relation is also shown in Figure 50; here the westward pitch of the structure makes the beds at the surface dip north toward the west (as in the Bangor Southern, which see) and south toward the east (as in the American Bangor quarry.)

Quarrying was begun here in 1875. After repeated periods of operation the quarry was finally shut down in 1914. The production included roofing slate, blackboards, and structural material.

51. *Bangor Southern Quarry.* This opening is N. 30° W. about 1.5 miles from Ackermanville, and west of the highway from Ackermanville to Pen Argyl. It measures 300 feet by 150 feet; approximately 20 feet of walls are exposed to water level, of which 15 feet are glacial overburden.

Beneath the latter the slate beds are seen striking N. 57° E., at the northern end of the opening the dip is 31° NW., but decreases southward to 20° . The cleavage strikes N. 65° E., dips 20° SE. Grain trends N. 43° W., and dips vertically. No jointing is seen.

It is said that at a depth of 180 feet the beds reverse so as to dip south below the water level. This might be expected if the dip at the American Bangor is considered. The beds worked were mainly in the Old Bangor “run”.

This quarry was opened in 1890 and shut down in 1895. In 1904-05 slate was removed under a lease from the American Slate Company. Then quarrying was abandoned and never resumed.

52. *Reichard Quarry.* About 400 feet N.57°E. from Quarry No. 53 is a small pit measuring 70 feet long by 30 feet wide, the greater length being northwest. The depth is 18 feet.

Thin beds of sandy slate are exposed striking N.46°E. and dipping 43°SE. The cleavage strikes N.70-80°E., and dips 20°S.

53. *Reichard Quarry.* This opening lies N.60°W. about 1,200 feet from the Bangor Southern, on the north slope of a small hill. It is about 100 feet by 40 feet, and roughly rectangular; the depth is 30 feet to the top of the rubbish which now partly fills the hole, but may once have been greater. In the wall the beds turn, dipping 68°N. at the south end and surface, whereas the strike and dip in the north end at the surface are N.50°E., 68°S. Below the surface the dip is everywhere south. Near the south end, therefore, an anticlinal axial plane, dipping south, emerges. The strata could not be definitely correlated with those of other quarries, but are presumably in the upper part of the Bangor beds. Cleavage strikes about N.45°E., dips 11°S. Grain trends N.47°E.

Several smaller openings are seen on the west slope of the hill on the north side of which this quarry lies. None are more than 5 feet deep and none show bedding.

54. *Delabole Quarry.* The old Delabole quarry is located about 1,200 feet N.25°E. from the station of Delabole on the Bangor and Portland (Delaware, Lackawanna & Western) Railroad. It is 250 feet long and 100 feet wide. The depth was probably at least 80 feet greater.

The beds strike N.50°E., and dip 62°N. at the north end of the opening, vertically at the south. The cleavage strikes approximately parallel with the beds, dips 12°S. These bedding-cleavage relationships suggest that the quarry is south of a south dipping synclinal axial plane. The beds are said to have been still vertical at the greatest depth worked. The strata exposed are not very thick. No single bed exceeds two feet. Some blocks on the dump show cleavage faces five feet "long". The beds opened were in the Grand Central and Old Bangor "runs". The grain trends N.47°W.

This quarry was opened in 1900 by Mr. William Blake of Bangor. After changing hands several times it was shut down in 1910 and work has not since been resumed. The production is said to have been mainly roofing slate.

55. About half a mile south of the Jackson Bangor No. 5 (Valley) quarry is a cut just east of the highway. This measures about 50 feet square and is 40 feet deep. Judging by the strike, the beds here must be about the same as in the Delabole quarry, described above. They vary in thickness up to 2 feet and strike N.67°E., dip 32°N. The cleavage strikes N.35°E., dips 12°S.

56. A small pit lies on the southeast flank of a round hill, just east of the Delabole station. The opening is about 100 feet long, 20 feet wide, and very shallow. On the same hill, northeast of this opening, there are several smaller prospects.

Beneath a shallow burden of decayed slate, the beds strike N.47°E., and dip 14°N. The cleavage strikes N.47°E., dips 10-15°S. Grain

trends N.47°W., and is vertical. The beds are very sandy, too much so to permit the development of good cleavage. They effervesce slightly with acid.

57. *Nagel Quarry.* This is a small opening about 400 feet due east of the south Uhler quarry and 1 mile east of Delabole. Glacial material, weathered slate, and water are seen in a small prospect, which is only 15 feet deep. Nothing is known of the history of the opening.

POINT PHILLIP GROUP.

Five soft slate quarries are located within a radius of three miles of the town of Point Phillip on the Delaware, Lackawanna & Western Railroad.

All the quarries are abandoned and in none could measurements of the successive beds be made in sufficient detail to establish their exact correlation. A study of the areal geology of the region, however, shows that all these openings, with the possible exception of the St. Nicholas and Beers quarries, lie so close to the north edge of the outcropping middle, sandy member of the Martinsburg that they are thought to have been opened in the Bangor, rather than in the Pen Argyl beds. This conclusion is favored by the sandy character of the slate. In all the quarries studied the beds dip gently and the cleavage more steeply south. The structures in all demonstrable cases thus appear to be the south limbs of (northward overturned) anticlines, having south dipping axial planes. No faults were seen, and a detailed study of the jointing was not made.

The products probably included only roofing slate, flagging, and fence posts; although the openings are in the soft belt, they are too small to have supported the extensive operations that justify the erection of a mill.

1.—2. *West End Quarries.* Two quarries, about 200 feet apart, are situated about a mile above Newtown up the valley of the west fork of the Bushkill. Both openings are approximately 100 feet square and both are full of water, so that no rock can be seen in place.

The slate found on the dumps north of these openings is somewhat calcareous and effervesces with acid.

These two quarries are said to have been worked last about 1900.

3. *Beers Quarry.* An old quarry lies 1.1 miles due north of Newtown on the west side of the road leading to Katellen. It is 120 by 40 feet in ground plan. The bedding could not be clearly distinguished but is described by Sanders¹ as having a strike of N.50°E., and a dip of 10°S.; the cleavage strikes N.87°E., dips 62°S. The slate lying on the dump to the south looks quite fresh and has the relatively thick beds and non-siliceous "ribbons" of soft slate.

The property belongs to Mr. Beers of Newtown. Operations were begun here as early as 1890, but the quarry has been abandoned for a long time.

4. *St. Nicholas Quarry.* About 500 feet southeast of the Beers quarry, on the east side of the Katellen-Newtown road and in the valley

¹ Sanders, R. H., *Geology of Lehigh and Northampton Counties: Pennsylvania Second Survey*, D 3, vol. 1, p. 103, 1883.

of Bushkill Creek, is another small opening, of about the size of the Beers quarry. The quarry walls are not visible, the hole being filled with water. The opening must be shallow, to judge by the size of the dump. The strike and dip are given by Sanders¹ as N.50°E., 15°S. Presumably the history of this operation is much like that of the Beers quarry. Typical soft slate is on the dump to the south.

The beds in which this opening were made are tentatively assigned to the Bangor group because of their nearness to the top of the middle, sandy member of the Martinsburg formation. This correlation cannot be established beyond question, however.

5. *Young Quarry.* This old opening is on the headwaters of Hockendauqua Creek, 1500 feet west of Stahley's Mill and one mile due west of Point Phillip. The dump and hole are hidden by timber from the road on the south. The quarry measures 100 by 120 feet and the estimated depth is 60 feet. Water conceals the bed rock except along the northwest side. There are several moderately thick beds, which, to judge by their sandy texture and their nearness areally to the belt of outcrop of the middle, sandy Martinsburg to the south, probably represent the Bangor beds. The strike is N.40°W., the dip 20°S. The cleavage strikes N.85°W., dips 37°S. These relations imply that the quarry is located near, but, probably slightly south of the axis of a westward pitching anticline. Production here ceased more than 25 years ago. Roofing slate alone was made.

SLATEFIELD GROUP.

The quarries of the Slatefield group are all within a mile south of Slatefield on the Lehigh & New England Railroad. This station or the town of Danielsville, about two miles northwest, would be the logical shipping points. They are all in the soft belt. Actual correlation with the standard section cannot be made with certainty, but by aligning these openings with certain quarries in the neighborhood of Danielsville, in which the Albion "run" probably occurs, it is thought that the southern quarries of the Slatefield group can with fair assurance be regarded as having been opened in the Bangor beds, while the Seip quarry is probably in the Pen Argyl beds. This interpretation is strengthened by the sandy character of the beds in the more southerly quarries of the group and by their proximity to the northern border of the outcrop of the sandy member of the Martinsburg.

The beds are variously folded. A striking characteristic is the uniformly steep cleavage dip and hence also the steep dip of the axial planes of the folds; cleavage planes are recorded as dipping 45-63°S. Jointing was not studied. No faults were seen.

None of these quarries are now operated, and there is no probability of the early resumption of work. None save the Labar quarry seems to have furnished much slate in recent years.

1. *Seip Quarry.* This opening is 1½ miles due west of the St. Joseph School. It is 125 by 60 feet in areal dimensions and not over

¹ Sanders, R. H., op. cit., p. 101.

60 feet deep. No slate is seen above the water with which it is filled. It was probably shut down about twenty years ago.

2. *Labar Quarry.* This quarry is 3000 feet due south of the railroad at Slatefield. It is about 255 feet long and 165 feet wide. Water fills the hole, but slate is well shown above it in the west corner. Here the beds strike N.67°E., dip 70°S., whereas the cleavage strikes N.60°E., and dips 55°S.; the grain appears to strike about N.20°W. and is vertical.

The slate seen in the west corner consists of alternating sandy beds 3 inches thick, with poor cleavage, and thicker shaly beds. Some good slate is seen on the large dump to the south. Two big beds yielding good slate are said to have been worked here.

The quarry was opened about 30 years ago and shut down about 1910.

3.—4. *Quarries.* These two small openings are on either side of the road, half a mile S.20°E. from the railroad at Slatefield. The hole 10 feet east of the road is 30 feet square. The depth does not exceed 30 feet. In the small exposure of slate on the walls, the beds strike N.70°E., dip 53°S.; the cleavage, N.65°E., dips 48°S. These relations suggest the north limb of a northward overturned anticline.

The small opening 10 feet west of the road is also filled with water. It measures 25 by 50 feet. No slate is seen in place.

5. *Langenbach No. 1 Quarry.* This quarry is situated 800 feet north of the Langenbach No. 3 opening. It is 100 by 130 feet and at least 100 feet deep, but now almost completely filled with water. An exposure on the east side shows beds which strike about N.80°E., and dip 13°S.; the cleavage strikes similarly and dips 63°S. The grain plane could not be determined.

The slate on the dump shows a tendency to break in well defined slabs parallel to the beds, is rather sandy, and exhibits catspaws. Its character suggests the Bangor, rather than the Pen Argly beds, an impression supported by its nearness to the sandy middle Martinsburg to the south.

About 300 feet north of this opening, and largely concealed by its dump, is a small cut showing slate strata, among which is a bed 3½ feet thick. Here the bedding strikes N.78°W., dips 15°S., whereas the cleavage strikes N.60°E., dips 45°S. The grain trends N.41°W., dips 80°S.

6. *Langenbach No. 2 Quarry.* This is a small hole about 400 feet south of the Langenbach No. 1 opening. Slate, some 20 feet in depth, is exposed along a side 30 feet long. The beds strike irregularly, due to slumping, the dip seems to be generally south from 5° to 25°, but the observations are poor. The cleavage strikes N.80°E., dips 70°S. One big bed 4 feet thick is seen at the bottom of the cut.

7. *Langenbach No. 3 Quarry.* This opening lies about three-quarters of a mile south of Slatefield. It is 70 by 180 feet in size and opposite sides are parallel. The depth is probably not over 40 feet. No slate shows above the surface of the water which fills the opening. The chips on the dump to the south have a good ring, show relatively little rusting, and bear no pyrite or quartz.

This and the two other Langenbach quarries were operated about 35 years ago.

8. *Williams No. 1 Quarry.* This opening is located on the Williams estate, about three-quarters of a mile west of Youngsville, in a field, 500 feet north of the road to Danielsville. It is 50 by 90 feet in size; there is water in the bottom, but some 15 feet of slate show in the walls. The beds seem to strike $N.70^{\circ}W.$, and to dip $10-20^{\circ}S.$ One big bed was quarried here, according to accounts given the writer. In 1892 the quarry was shut down.

9.—10. *Williams No. 2 Quarry and Shaft.* Two small, shallow pits, about 10 feet apart, are located about 300 feet east of the opening last described. Of these the east one is 40 feet square, the west approximately the same size and probably deeper. Both are filled with water. The westerly opening shows in its southwest wall some slate, of which the strike and dip of the beds is $N. 80^{\circ}W.$, $23^{\circ}S.$; that of the cleavage is $N.72^{\circ}E.$, $62^{\circ}S.$

Approximately 70 feet southwest of these openings is a shaft. This is said to have been worked to follow the big bed opened in the Williams No. 1 quarry. It is 40 feet deep and 300 feet $S.80^{\circ}E.$ from the Williams No. 1 opening.

PORTLAND GROUP.

The four quarries of the Portland group are grouped together because their industrial center would normally be the town of Portland. Three of the quarries lie south of the limestone valley that extends west from Portland; the fourth is north of this limestone area. All the openings are in the hard belt and have produced typical hard slate, closely banded, with many thin beds of highly siliceous slate, and with carbonaceous layers less conspicuous than in the soft belt. As the detailed sequence of the beds in the hard belt has not been worked out, the exact stratigraphic location of these quarries is in doubt. The Mount Bethel quarry is probably in strata considerably higher than those of the others.

As will be recalled, the smaller folding in the hard belt is generally intense and these quarries show no clear relation to major folds. It is a striking fact, however, that the cleavage in all three of the openings south of the limestone belt at Portland has a steep dip, from 30° to $55^{\circ}S.$, which suggests that the fold axes are here more nearly upright than ordinarily. No faulting is seen in any of the openings. No generalizations can be made in regard to joint systems.

The products of these quarries were roofing slate, grave vaults, slate flagging, and fence posts. None of the product was milled. Of the four pits described none are now operating, nor is there a probability of the early resumption of quarry work.

1. *Northampton Quarry.* This is a small quarry in the hard belt situated about a mile north of Portland and approximately 800 feet west of the Portland-Stroudsburg highway on the slope of the hill forming the west bank of the Delaware River Valley. It measures 35 by 15 feet, is roughly rectangular in outline, and shows 20 feet of slate in the walls. The bottom is filled with water.

The slate has the typical thin bedding and siliceous "ribbons" of the hard belt. In the bottom of the opening the strata strike $N.80^{\circ}E.$, dip $42^{\circ}N.$; the cleavage planes strike due east and dip $20^{\circ}S.$ Grain trends $N.42^{\circ}W.$, and dips $80^{\circ}SW.$ In the wall of the quarry the beds turn over so as to lie horizontal at the surface.

The quarry was probably opened since 1880. From a theoretical viewpoint it is of great importance in interpreting the structure of the region, because it clearly demonstrates the existence between Portland and Slateford of a strip of the lowest member of the Martinsburg formation.

2. *Mt. Bethel Quarry.* This opening is located in the field back of the Mount Bethel Church. It measures 90 by 75 feet and is rectangular in outline. As the quarry is filled with water, the depth cannot be determined, but was estimated to be 60 feet.

The slate is typical of the hard belt, closely "ribbed," and tending to "rust" on exposure. The bedding strikes $N.65^{\circ}E.$, dips $12^{\circ}S.$; the cleavage strikes parallel with the beds and dips $53^{\circ}S.$,—an exceptionally high dip, perhaps induced by the nearby major faulting between this opening and the limestone to the north. The grain plane is not clear, but seems to trend $N.30^{\circ}W.$

The quarry has not been operated in many years.

3. *Phillips Quarry.* This is the eastern of two quarries which, about 600 feet apart, are situated on adjacent farms about four-fifths of a mile due east of Mount Bethel. The Phillips quarry is 130 by 65 feet in size and rectangular; it is 25 feet deep to the level of the water standing in the bottom, and probably extends 15 feet deeper.

The slate seen is typical of the hard belt, closely ribbed and with rather papery weathering, but apparently subject to but little rusting. At the surface the beds near the west corner of the opening strike $N.65^{\circ}E.$, and dip $35^{\circ}S.$, but flatten lower down, so as to dip only 5° . Farther south the dip is steeply northwest. The quarry is thus in the trough of a small asymmetrical syncline, the south limb of which has the steeper dip. The cleavage (and the axis of the fold) strikes $N.42^{\circ}E.$ and dips $55^{\circ}S.$, an unusually steep dip, such as was also seen in the Mount Bethel quarry. The grain strikes $N.38^{\circ}W.$ Prominent joints strike $N.80-90^{\circ}W.$, and dip $70-90^{\circ}NE.$ A less conspicuous system strikes $N. 20^{\circ}W.$, dips $50-60^{\circ}S.$

This quarry has not been worked since 1910 at the latest.

4. *Miller Quarry.* This opening is almost triangular in form, its longest side being 190 feet. The greatest depth of the walls is 20 feet to water level, but the opening is probably at least 40 feet deeper.

The slate shows papery weathering, but is otherwise good. The beds in the northwest corner strike $N.10^{\circ}W.$, dip $35^{\circ}SW.$; cleavage strikes $N.63^{\circ}E.$, dips $30^{\circ}S.$; grain trends $N.40^{\circ}W.$, and is generally vertical. The structure appears to be the axis of a west pitching anticline, probably complementary to the syncline seen in the Phillips quarry. Two sets of joints, both striking $N.60^{\circ}E.$, but one dipping $80^{\circ}N.$, the other $65^{\circ}S.$, show clearly on the southwest wall and were probably formed simultaneously. Their general parallelism with those observed in the Phillips quarry is noteworthy.

Between 25 and 30 years ago the quarry was operated under lease.

UNCLASSIFIED.

Quarry. About six-tenths of a mile due west of the road intersection at Johnsonville (Delaware Water Gap sheet) and about 400 feet north of the highway, on the farm of Mrs. Miller, is a hole now full of boulders and showing slate only in fragments, not in place. The slate chips appear to be closely ribboned, like hard slate, but it is thought that this opening, like the Batt quarry south of Wind Gap, is in a lens of slate beds between the sandy layers of the middle Martinsburg. This opening is said to have been worked for slate on a small scale some time ago.

South of the residence of Mrs. Miller two openings were once operated, and closely ribboned hard belt slate was obtained. These old excavations are now filled up.

FLICKSVILLE GROUP.

Several quarries are dotted over the outcrop of the hard belt in the neighborhood of Factoryville and Flicksville. Normally their shipping center would be Flicksville, on the Martins Creek branch of the Bangor & Portland (Delaware, Lackawanna & Western) Railroad.

The slate in these quarries is in the hard belt, but some of it is characterized by especially thick beds, suggesting those in the Batt quarry. The exact stratigraphic position of these quarries cannot be determined.

Several of the openings display complex folding of the beds around axial planes that are almost horizontal. Otherwise no general statement as to the folding involved can be made.

The cleavage shows the usual strike, generally N.60-80°E. A fairly generally developed system of joints strikes approximately due north, dips vertically or nearly so.

The quarries of this group have not been operated in several years and many of them were opened long ago. All are now abandoned. The openings, with the exception of the True Blue quarry, are not large and their production was relatively unimportant. The yield was roofing slate, fence posts, flagging, and grave vaults.

1. *Pysher Quarry.* This small and long abandoned opening is one mile ENE. from Flicksville in a field about 150 feet east of the road.

The hole is triangular in outline and 5 feet deep to water level, but thought by Mr. Pysher to be 22 feet deep to the actual bottom. The beds dip gently south; the strike, however, could not be measured. cleavage strikes N.48°E., dip 40°S.; presumably the structure here is the north limb of an anticline.

The quarry was opened 40 years ago and worked for 3 years. Roofing slate was produced for local use only, an old-fashioned horse derrick being employed in quarrying.

2. *Doster Quarry.* This opening is on the Doster estate, about 800 feet up the valley of the small stream that crosses the highway 2000 feet south of Flicksville. The opening is 80 feet in diameter and roughly circular. The maximum depth is probably 60 feet.

The slate is typical, closely "ribboned" hard slate. The beds could not be distinguished with certainty but the dip seems to be 12°S. The cleavage strikes N.70°E., dips 28°S. Grain trends N.53°W., dips 70°

E. Twelve joints were counted, seven striking about due north and dipping vertically, and five striking N.75°E., also vertical in dip.

No slate has been quarried here for over 30 years.

3. *Wagner Quarry.* This pit lies seven-tenths of a mile south of Flicksville, 70 feet east of the main Martins Creek highway. It is a circular hole 50 feet in diameter, and 50 feet deep at most. A little slate shows in the inaccessible southeast wall.

Slate was first quarried here in 1875 but operations ceased after 3 years without commercial production.

4. *True Blue Quarry.* This opening lies about a quarter of a mile NNE. from Nazareth Junction, and west of the Martins Creek highway. It is 185 feet by 275 feet in size, and filled with water so that the true bottom is not visible and only 15 feet of slate are exposed in the walls.

The slate is typical, closely "ribbed" hard slate. It is partly sandy and "rusts" (turns brown) somewhat upon weathering. The best beds are on the southeast. Pyrite is not uncommon and upon weathering yields a film of iron sulphate on the reentrants of the quarry walls.

At the surface the strike is N.60-80°E., and the dip is 35°S. near the north end of the northeast wall, but can be seen to reverse to a north dip about 10 feet below the surface, then to dip south again near the bottom of the opening. Cleavage strikes N.65-75°E., dips 35-40°S. In places quartz stringers parallel the cleavage planes; this is especially noticeable on the southeast wall. The grain strikes N.60°W., dips 70°NE. In the northeast wall joints trend N.10°W., dip 75°SW., and are very conspicuous.

This quarry was opened about 1865 and operated intermittently. After a change in leasehold, followed by a few years of operation, it finally shut down. The products included grave vaults, grave covers, and roofing slate.

5. *Friedman Quarry.* The Friedman quarry is on the hill slope west of Martins Creek, and 1,500 feet due west of the True Blue quarry. It is 45 by 60 feet in size and 25 feet deep to water level.

The slate is typical hard slate, closely ribbed and siliceous. The beds strike N.78°E., dip about 8°S., but were not accessible for accurate measurement. The cleavage dips 27°S., strikes N.85°W. Grain appears to trend N.55°W. A set of joints strikes N.55-60°E., dips 80-90°N.

The quarry was opened on a lease about the year 1910, but no slate was ever sold.

6. *Delabole Quarry.* A hard belt slate quarry lies 1.1 miles due west of the crossroads at Factoryville, in the valley of a small stream, about 1000 feet from the Werkheiser-Factoryville road. It measures about 150 by 80 feet, and is probably 75 feet deep.

The slate on the dump suggests somewhat that seen at the Batt quarry, 1½ miles south of Wind Gap. The largest bed is 2 feet thick, and there is much close "ribboning" with highly siliceous laminae; some carbonaceous "ribbons" up to 2 inches in thickness occur.

As no slate outcrops, the actual dip and strike of beds could not be

determined. Sanders¹ gives the bedding as striking N.60°E., dipping 80°S.; the cleavage strikes N. 60°E., dips 25°S. The grain, to judge by the form of the quarry is N.38°W. Quarrying was begun here about 1875. No machinery remains on the dump.

BELFAST-EDELMAN GROUP.

The quarries of this group are within a radius of 2½ miles of the village of Edelman on the Delaware, Lackawanna & Western Railroad. All are most convenient to this railroad; shipments may be made from Rasleytown, Edelman, Werkheiser, or Belfast Junction. Supplies are purchased from Belfast, and here also reside the quarry workmen.

All these quarries except the Batt quarry are in the hard belt and produce typical hard slate. Some, like Number 18, 19 and 20, are low down in the lowest member of the Martinsburg, but others are operating in much higher beds. The Batt quarry is thought to have operated in a lens of rocks similar in most qualities to hard slate, but lying between beds of middle Martinsburg sandstone.

The structures exposed in the openings are too variable to permit any generalizations. The strike of the bedding is commonly about N.80°E., whereas the cleavage tends to have a more northerly course and dips gently south.

In at least two quarries there are illustrations of movement along cleavage planes, such as were described on page 169 and might be called "cleavage plane slip." A movement of this type is described from the Edelman and Belfast quarries, and is thought to be present at depth in the Northampton quarry.

On the whole, it may be said that in these quarries the jointing is very regular. One joint system is especially prominent in all openings,—that striking N.55-80°E. and dipping vertically.

In the openings of this group, production, being entirely hard slate, is confined to roofing slate, slabs, fence posts, grave vaults, and rarely, table tops; of these, roofing is by far the most important.

Only two quarries have been active lately, the main Belfast quarry and the Edelman quarry. A small production in the early part of 1923 came from the Theo. Whitesell and Northampton quarries.

1. *Batt Quarry.* This old quarry is eight-tenths of a mile N.60°W., of the church at Rasleytown. It is 60 by 100 feet in size and filled with water. The beds strike due east, and are closely folded. Cleavage strikes N.70°W., dips 10°S. Grain trends N.47°W. Well developed joint planes strike N.37°E. and dip vertically; one such forms the northeast side of the opening.

The "ribbons" in this slate show much more carbonaceous matter than is usual in the hard belt, yet are closely spaced and generally half an inch or less in thickness. The slate gives the appearance of being intermediate in character between the slates of the hard and soft belts. It is thought that this opening is in a lens of slate between the sandy beds of the middle member of the Martinsburg formation.

The quarry is on the old Batt farm. It was operated about 30 years ago.

2. *Garr Quarry.* This opening, which is 175 by 125 feet, lies on

¹ Sanders, R. H., op. cit., p. 98.

the west bank of Bushkill Creek and east of the Delaware, Lackawanna & Western Railroad, about three-quarters of a mile south of Rasleytown. The hole is now filled with water. The beds just across the stream here strike N.75°E., dip 75°S., while the cleavage strikes N.85°E., dips 35°S.; presumably the same structure is present in the quarry here described.

The slate on the dump has a good ring, and shows relatively few ribbons for hard slate; quartz veins are common. The quarry was last operated in 1912.

3. *Lehr Quarry.* About 1,000 feet N.80°W., from Edelman there is a quarry measuring 90 by 70 feet and about 40 feet deep. The beds strike N.48°E., dip 10°N.; cleavage strikes N.82°W., dips 18°S.

The quarry was opened in 1900 and shut down in 1907. Some roofing slate is piled on the dump.

4. *Edelman Quarry.* This quarry is about 300 feet west of the railroad and 500 feet north of the station at Edelman, measures 200 feet N.48°E., by 225 feet N.38°W., and attains a maximum depth beneath water level of 150 feet.

The beds are thrown into a series of open folds with horizontal axial planes, two adjoining anticlines and the intervening syncline being visible on the northwest wall. In one place the thickening produced by such folding swelled a bed 3½ inches thick where the dip is 30° (that is, on the limb) to 7½ inches on the axis of the fold.

The strata in the present working level strike N.65°E., and dip variously. The cleavage strikes N.65-80°W., dips 10° or less to the south. Grain trends N.53°W. A series of joint strikes N.10°E., dips 45-55°S.; another system strikes N.55-70°E., dips vertically, and cuts off the joints of the set first mentioned.

In addition, the old hole, especially along the western walls, shows an almost flat-lying slippage plane striking N.65°E., and dipping 8-10°S., and thus parallel with the cleavage. In the present working level a similar plane is seen. Here the cleavage is curved, and there is evidence of movement along a series of closely spaced cleavage planes. A stringer of quartz and coarsely crystalline calcite follows this disturbed zone; at intervals the wrinkling of the cleavage is unusually conspicuous and a spherical or lenticular mass of calcite and quartz, irregular in outline and generally elongated parallel to the cleavage, if at all, appears. Plate 11, A shows a similar feature as seen in the Belfast quarry (see p. 263).

This quarry was opened by the pioneer quarryman Edelman, after whom the railroad station was named, about the year 1870, abandoned in 1900, and reopened in 1923 by the Theo. Whitesell Hard Vein Slate Company. Roofing slate alone is now produced.

5. *Barnett Quarry.* This small prospect lies about 840 feet N.75°E. from the Edelman station on the Delaware, Lackawanna & Western Railroad. It is about 30 feet deep. The beds strike N.80°E., dip 12°N.; the cleavage strikes about due east, dips 20°S. The opening was last worked in 1887.

6. *Pennsylvania Quarry.* The opening is immediately east of Little Bushkill Creek, 500 feet south of the Edelman station. The measure-

ments are 300 by 250 feet. The strike and dip of bedding and cleavage, respectively, are N.80°E., 15°N., and N.50°W., 40°S. The slate seems to be good except for pyrite and calcite along fractures. Quarrying was begun in 1895, but the pit has long been abandoned.

7. *Seem Quarry.* This and the Allen quarry lie 1,200 feet west of the Little Bushkill and equally distant from Edelman and Werkheiser on the Delaware, Lackawanna & Western Railroad. The northern opening is the Seem quarry. It measures about 150 by 100 feet and is separated from the Allen quarry by a wall 8 feet wide along its southwest side. The depth is not known, but 25 feet of slate show above water level. At the surface the hard slate beds strike N.80°E., dip 20°N.; the cleavage strikes N.50°W., dips 13°S. Prominent joints trend N.60-80°E. and dip vertically. The quarry has not been in operation for the last 20 years.

8 *Allen Quarry.* This lies close to the Seem quarry; the wall that forms the southwest edge of the latter is the northeast side of the opening here described. The Allen quarry is a rectangular hole about 100 feet square, with a projection from the south corner. It is said to be the deeper of the two openings. It shows the same structural features as the Seem quarry. Operations ceased about 1912.

9 *Northampton Quarry.* This is a large opening at least 175 feet deep to water level, and said to have been 350 feet deep when working. It is 500 feet northeast of the station of Werkheiser on the Delaware, Lackawanna & Western Railroad. In ground plan it is rectangular and measures 400 by 225 feet, the longer dimension extending N.55°E. A smaller quarry, 100 by 200 feet in size, lies 400 feet SE. of that described.

The general strike of the beds in the large opening is N.80°E. to N.80°W. The dip is very variable, being generally northward, with repeated close folds. Cleavage strikes N.50°E., dips 5° to 10°S. At depth the cleavage is good, apparently beneath a flat joint or cleavage plane that bears calcite and closely resembles the cleavage slip seen in the Edelman quarry. The close jointing proved disadvantageous to quarrying. The bottom is not accessible and was therefore not studied in detail.

The smaller hole shows beds striking due east, and dipping 12°N.; the cleavage strikes N.70°E., dips 12°S. There is less overfolding here than in the larger quarry. Vertical joints, tending to curve downward, strike N.55°E. There are also numerous minor curved joints which seriously interfered with quarrying.

These openings were made by the Northampton Hard Vein Slate Company in 1885. Work went on until the spring of 1923, even through the period of the Great War, but the partnership was dissolved in 1924.

10. Just south of the road from the Northampton quarry to Werkheiser, and east of Little Bushkill Creek, is a small opening 60 by 80 feet in ground plan. The beds strike N.80°E., dip 65°N., with at least one close fold showing in the north wall. Two N.60°E. joints are seen. Some good roofing slate lies on the dump.

11. In the valley flat, just west of the Little Bushkill and about half

a mile south of the station of Werkheiser, is an old slate quarry measuring 70 by 40 feet in area. It is said to have been 65 feet deep but water now fills it to the top. A few old slates on the dump seem to be of good quality. It is said that a drill core was obtained in this opening and at 50 feet below the quarry bottom (total depth 115 feet below surface) a plane of movement with clayey gouge and closely spaced joints was encountered. This apparently represents another cleavage slip. The opening has long been deserted.

12. *Theo. Whitesell Quarry.* This large opening is about 4,000 feet S.30°E. from the station of Werkheiser and 2,000 feet east of Little Bushkill Creek. It is irregular in shape and measures roughly 240 feet N.20°W. by 285 feet N.50°E. The beds are virtually horizontal. There is none of the repeated overfolding seen in the Northampton quarry. The "ribbons" seem to be somewhat farther apart, and less conspicuous than in most hard slate. The cleavage strikes N.80°E., dips 18°SE. Grain trends N.50°W. Prominent joints strike N.75°E. to N.80°W., with dips varying from 70°S. to vertical. A less conspicuous system strikes N.70°E., dips at angles of about 45°N. A few irregular joints strike N.30°E. The two main systems are closely contemporaneous, as they cut each other indiscriminately. The outstanding feature of these joints is their general parallelism in strike.

This quarry was operated by the Theo. Whitesell Company of Easton. The work ceased in 1924. A full line of roofing slate was produced.

13.—14. Two small prospect pits lie immediately east of the Theo. Whitesell quarry. The northern is by far the larger opening. In it the beds are horizontal and the cleavage strikes N.80°E., dips 18°S. The grain trends N.40°W., dips steeply northeast. A set of joints striking N.80°E., and dipping 80°S. is conspicuous.

15. *Pritchard Quarry.* This old, deserted quarry lies S.25°E. of the station of Werkheiser, up a small valley that enters the Little Bushkill from the east. Its maximum dimensions are 200 by 80 feet and water rises to within 5 feet of the surface. The slate is typical hard slate, closely banded. The bedding strikes N.72°E., and dips 15°N. Cleavage planes strike N.35°E., dip 18°S. The quarry was operated in the years 1854 to 1878, but is now abandoned.

16. *Old Belfast Quarry.* This small quarry lies 700 feet west of the Belfast-Wind Gap highway, due west of the Belfast school. It measures 85 by 125 feet. The depth is 20 feet to water level, but probably extends 60-80 feet deeper.

The bedding is horizontal in the south end of the opening and dips gently north at the north end. The cleavage strikes N.80°E., dips 28°S.; grain trends N.48°W. A system of prominent joints, striking N.55-70°E. and dipping vertically or nearly so is well developed; joints of this set form the longer walls of the opening.

17. *Belfast Quarry.* This large quarry lies due west half a mile from the schoolhouse in Belfast, north of the road from Belfast to Jacksonburg, and east of Bushkill Creek. The opening, with several jogs in its walls, is roughly rectangular, measuring in ground plan 185 feet by 137 feet. It is about 150 feet deep to the lowest level, which



A. Jointing in northeast side of Belfast quarry, looking N.75°E. from middle of southwest side; several major joints strike N.70°E. and dip almost vertically.



B. New bench or "piece" and old opening of Edelman quarry near Edelman Station.

is partly under water. Operations have progressed on several sub-levels.

Fresh slate, suitable for sale, is quarried 15 feet below the surface. The beds are typical hard slate; on the lowest level they are somewhat more siliceous and not profitably quarried. At the surface the strike is $N.80^{\circ}W.$, dip $7^{\circ}N.$ On the next lower level the dip and strike are similar, but on the lowest working level (depth 100 feet) the strata take a sharp turn, dipping first $20^{\circ}N.$, then, at a depth of about 120 feet, $45^{\circ}S.$, and finally, in the very deepest part of the quarry, being again reversed, $3^{\circ}N.$ Approximately the same strike is maintained by the beds throughout.

The cleavage strikes approximately due east, and varies in dip from 5° to $22^{\circ}S.$ Grain trends on an average $N.40^{\circ}W.$, and is vertical. The jointing in this quarry is very regular. All joints strike northeast, and by far the greater part between $N.60^{\circ}$ and $30^{\circ}E.$ The dips are generally steep, varying between 65° and $90^{\circ}S.$ Between two larger joints it is common to find a set of smaller compensating joints, their strikes making angles of 45° or less with the main joints and their dips about the same in magnitude and direction as those of the latter.

About 5 feet below the lowest working level and 10 feet above it respectively are two "floors" (in the vernacular of the quarrymen) or cleavage slip planes. Plate 11, A, is a photograph of the lower cleavage slip. This is a zone about 10 inches thick (at right angles to its plane) and parallel with the cleavage. Above and below it the slate is solid and the beds dip $20^{\circ}N.$, the cleavage $20^{\circ}S.$ In the cleavage slip itself the movement has accentuated the cleavage, so that the slate breaks into thin slivers. There is little tendency for cleavage planes actually to curl, but they are more irregular than those beyond the zone of the slip. The slip zone contains lenticular masses of quartz with carbonaceous and sericitic inclusions, the lenses being inclined southward more steeply than the cleavage. These relations, as well as the offsetting of joints above and below the zone of movement and the fact that the beds above the zone dip north while those below dip steeply south, suggest that there has been horizontal movement along the cleavage slip zone, the upper side moving north.

In the higher of the two zones of movement there are not merely quartz lenses, but quartz-filled gash joints, dipping parallel with the lenses. In this case the joints above the slip zone are offset northward 4 inches above those below.

Numerous irregular joints or "scows," roughly parallel in strike with the grain, but dipping $30-60^{\circ}NE.$ or $SW.$ are also seen in this opening.

Slate was first quarried here in 1884 by Amen Hughes; operations have been discontinuous since then. From 1918 to 1926 they were continuous, but in the latter year quarrying was stopped. The products have included roofing slate, flagging, fence posts and grave vaults. Fence posts were sold here in 1924 at about 30 cents apiece.

18. At Belfast Junction, 200 feet south of the secondary road that crosses the Little Bushkill here, and east of the stream, is a small rectangular opening, 25 by 30 feet in areal dimensions and 25 feet deep. Slate showing on the walls strikes $N.60^{\circ}E.$, and dips $20^{\circ}S.$, but Mr. R. S. Whitesell of Easton asserts that cement rock was encountered at

depth. It thus appears that the opening is near the base of the Martinsburg formation.

19. *Henry Quarry.* This old opening is 2,000 feet southeast of Filetown and about $1\frac{1}{4}$ miles due west of Belfast Junction. It is about 80 by 120 feet in area and approximately 40 feet deep.

In the northeast corner the cleavage strikes $N.50^{\circ}E.$, dips $13^{\circ}S.$ The bedding is nowhere accessible to accurate measurement, but appears to strike about $N.65^{\circ}E.$, with a dip of $50^{\circ}S.$ Grain trends $N.48W.$, dips $80^{\circ}S.$ Some poorly developed joints strike $N.80^{\circ}W.$ and are vertical. The slate on the dump shows moderately thick beds. Some roofing slates, already punched, were also to be seen. The quarry was last operated about 40 years ago. The product was good roofing material that found much favor, especially in Nazareth.

20. Halfway between Filetown and Cherry Hill and about 300 feet northwest of the road, is a small opening measuring 35 by 15 feet and 5 feet deep to water level. The beds strike $N.70^{\circ}E.$, dip $40^{\circ}S.$, whereas the cleavage strikes $N.80^{\circ}E.$, dips $11^{\circ}S.$ Typical hard slate is exposed. The structural relations are those of the north limb of a northward overturned anticline. The opening is clearly no more than a prospect. Its history is not known.

CHAPMAN GROUP.

A number of quarries in the hard belt are scattered throughout the area drained by Monocacy Creek and lying between the outcrop of the "cement rock" or Jacksonburg limestone to the south and the southern fringe of the middle, sandy member of the Martinsburg formation. They are lumped together under the title of Chapman group, merely because the present (and probable future) production centers around the station of Chapman, on the Lehigh & New England Railroad (Figure 64). The most logical and common commercial center for the quarries, however, is the town of Bath.

The beds exposed are all in the hard belt, and, as the separate beds bear no marks by which they can be readily distinguished from those above and below, the correlation of the strata in one quarry with those in another is impossible. The hard slate member is thrown into repeated folds, which, though generally small, are, as far as the quarries expose them, not very "tight," that is, they have large opening angles. The cleavage is regular, and generally strikes $N.55-80^{\circ}E.$, with gentle south dips.

Faulting is rare, only one case being recorded, and even in this instance the displacement does not exceed a foot. Some slippage along cleavage planes is suggested in the Chapman Standard quarry and in the two Chapman quarries.

The jointing was studied in great detail only in the three openings just mentioned; the strike of most of the joints is about $N.60^{\circ}E.$, and dips are vertical. This system is not conspicuous, and is generally compensated by joints with similar strikes but gentle dips.

The grain, as usual, trends northwest.

The outstanding products of the Chapman group of quarries is roofing slate of the typical "ribboned" variety, but slate for various structural purposes for which milling is not needed is also obtained. This includes grave vaults, fence posts, and wall boards.

12°N.; the cleavage strikes N.60°E. (?), dips 5°S. The slate appears to be of good quality, but very irregular joints, which probably hindered quarrying, are seen on the walls.

3. *Ryan Quarry.* This opening is 1,200 feet due west of the Chapman Standard quarry and is west of the road from Chapman to Kleeknersville. It is 200 feet square. The depth was at least 75 feet.

In the southwest corner of the quarry a little slate is seen. It is closely "ribbed" and appears to be of good quality, with no excess rusting, quartz-filled crevices, pyrite, or curved cleavage. The beds, though not accessible, are estimated to strike N.70°E., and to dip 40°N. Cleavage appears to dip 7°S. Grain trends N.38°W. A very regular vertical joint, striking N.60°E., forms the southeast quarry wall. Quarrying was discontinued in 1893.

4. *Bethlehem Quarry.* This quarry is about 400 feet southwest of the Chapman Standard and just north of the road from Chapman to Kleeknersville. It is 160 by 60 feet in size, and is filled with water, though some slate shows above water level on the sides.

The rock exposed is typical of the hard belt. At the highest point in the quarry wall the beds strike N.70°E., dip southeast about 40°, then the dip decreases, and steepens again lower down (see Figure 65); in this folding there is a notable lack of thickening of beds on the crests and troughs.

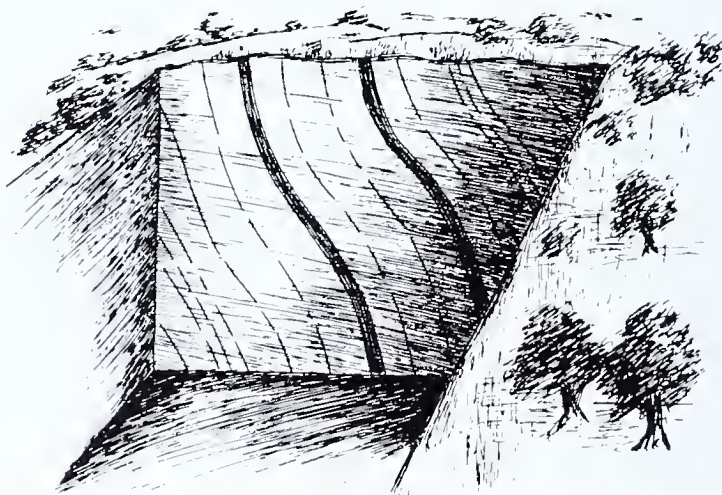


Fig. 65. Northeast wall of Bethlehem quarry, to show turn in dip of beds. From southwest side of opening.

The cleavage strikes N.57°E., dips 18°S. Grain trends N.40°W. The joints are notably regular and fall into one system; all major joint planes strike N.62-68°E., and are vertical. Between these major fractures there are commonly minor crevices striking N.50-60°E., which stop abruptly at their intersections with the major fractures.

This quarry was opened before the Chapman Standard, and work was abandoned approximately at the time of the beginning of operations in the latter quarry.

5. *Chapman Standard Quarry.* The Chapman Standard quarry is one of the few in the Chapman group that has been operated in recent

years. It is 250 feet southwest and virtually along the strike from the large Chapman quarry. In ground plan it is a rhombic opening about 250 feet on each side.

The strata exposed are all typical of the hard belt, being closely "ribboned," with many siliceous layers and only a few beds exceptionally rich in carbonaceous matter. The opening exhibits well the folding characteristic of the lowest members of the Martinsburg formation. At the very surface, in the north corner, the strike is $N.80^{\circ}E.$, and the dip $75^{\circ}S.$, but in the south corner the dip is north, owing to the emergence between these points of an anticlinal axis that dips south. Midway along the northeast side, a synclinal axis is encountered in the descent. Below this, at 50 feet of depth another anticlinal axis is seen, and at a depth of 80 feet one more syncline, the beds here striking $N.75^{\circ}E.$, and dipping $80^{\circ}N.$ These folds (see Figure 66) are open, with little thickening, if any, on the crests and troughs.

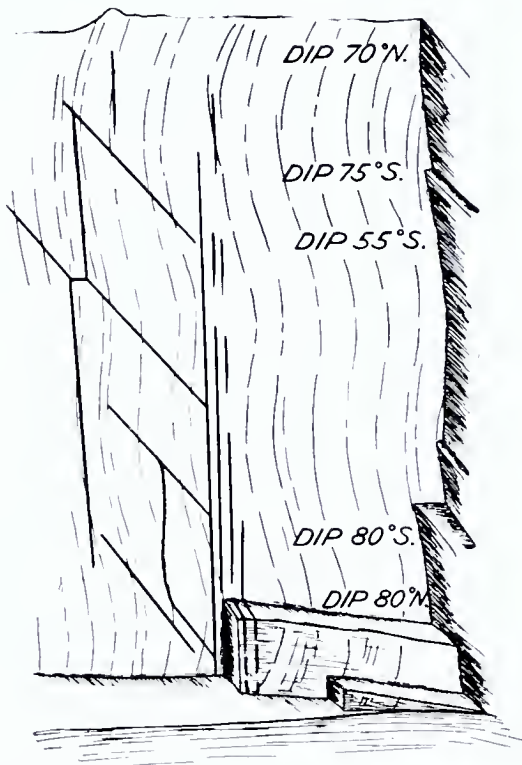


Fig. 66. Sketch of northeast wall at east corner of Chapman Standard quarry, as seen from floor of quarry; shows changes in dip of bedding, and intersection of joints dipping $45^{\circ}S.$ with others dipping vertically.

The cleavage strikes $N.60-70^{\circ}E.$, dips about $15^{\circ}S.$ wherever observed. Some is curved. Grain trends $N.50^{\circ}W.$, and is vertical. Jointing was studied in detail. Of 23 joints recorded in the bottom, 20 strike between $N.53^{\circ}$ and $80^{\circ}E.$; all except one have a dip of 60° or more, although the direction of dip varies, being about equally distributed between north and south. Four of the prominent $N.58^{\circ}E.$ joints are continuous from top to bottom of the opening. The more nearly vertical joints not uncommonly pass up or down into less steeply dip-

ping joints, with which they unite. In other cases they are offset by and themselves offset the joints of lower dip. The joint surfaces are not uncommonly coated with quartz or calcite; the calcite coats the sides of the joint crevices, the quartz being central; this relation is interpreted as meaning that the quartz was the last mineral deposited.

A noteworthy feature is the presence of two cleavage slip planes, one about 20 feet, the other 30 feet below the surface. Neither is accessible, but show a white mineral (quartz?) in the zone of the plane. Neither gives absolute evidence of movement and both are crossed by all major joints, though a few less conspicuous fractures stop at these planes.

The Chapman Standard quarry was opened in 1860. After a long period of operation by the Chapman Standard Slate Company of Philadelphia, it was purchased in 1926 by the Chapman Slate Company. The products have included roofing slate and some slate slabs.

6. *Chapman Quarry.* Two large holes constitute the workings of the Chapman Slate Company, one of the oldest producers of slate in Northampton County. They are almost continuous, being separated by a wall of rock only about 50 feet wide. They lie between and along the strike of the Keystone and Chapman Standard quarries, and roughly 1,200 feet north of the Chapman station. The west opening is the smaller. It is roughly rectangular, about 450 feet long by 300 feet wide, and 130 feet deep. The east opening is irregular in shape, has about the same width, but is 1,000 feet long, and rivals the largest quarries in the Bangor and Pen Argyl districts in volume; its depth is 150 feet. At present much of each of the openings is filled with waste and water stands in the bottoms of both. In 1924 quarrying was in progress at the southwest end of the west hole on two step-like levels beneath the surface, and at the northeast end of the east hole on two similar levels.

The geology of these two openings cannot here be described in great detail, but the outstanding features may at least be mentioned. A separate description is merited for each opening.

The southwest quarry shows slate under an 8 foot overburden of clay set with slate chips. The beds at the surface strike N.60-70°E., and dip 30°S. in the south corner. Approximately the same strike is preserved throughout the depth of the openings, but the dip reverses itself several times; in fact, parts of the two anticlinal folds that were described in the Chapman Standard quarry are visible in the northeast wall, with this difference, that the greater erosion and the depth in the Chapman quarry caused the surface to be carried beneath the highest anticline of the Chapman Standard and there is displayed instead, an anticlinal axis at the very bottom of the openings, where the beds dip 80°S.

As the planes of these folds strike N.70°E., whereas the greater part of the southeast quarry wall trends N.60°E. along a joint, traces of these folds on the southeast quarry wall give the effect of half-eclipses instead of arcs of circles, such as they really are, and of great flattening and thickening in the troughs and crests (see Plate 53, A); however, both these impressions are seen to be incorrect when the northeast wall is viewed along the strike (Figure 67).



A. Surface of conspicuous joint striking $N.60^{\circ}E.$, on southeast side of west opening, Chapman quarry; to show projections of folds on this surface.



B. Southwest wall of west opening of Chapman quarry, as viewed from north corner; to show the influence on quarrying of the strong joints striking $N.65^{\circ}E.$ and dipping vertically.

The cleavage strikes generally about N.70°E., dips 12-20°S. Grain trends N.41°W., and is vertical.

Joints form many of the smooth faces seen on the quarry walls. The most conspicuous strike N.60-70°E., dip vertically or steeply to the north. Locally these pass downward into joints of lower dip, but more commonly they hold their courses across the more gently dipping joints. One of the vertical joints forms most of the southeast, and another much of the northwest walls, and two others pass completely across the quarry. Minor, compensating joints strike parallel, but dip 33-60°S. These are generally cut by the joints having the steeper dip. The pattern outlined is very closely similar to that seen in the Chapman Standard quarry. Some of the joint planes bear coatings of fibrous calcium carbonate.

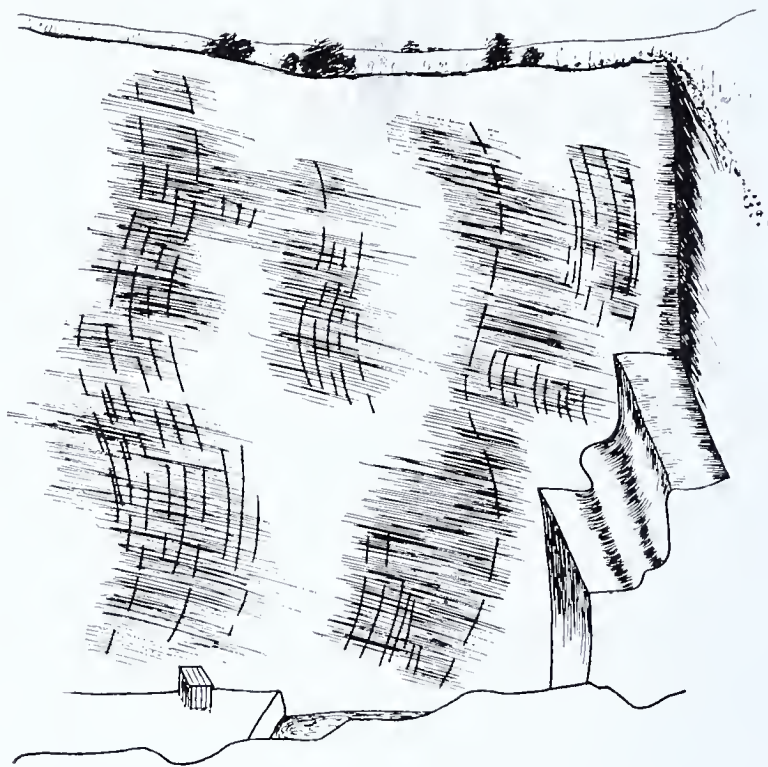


Fig. 67. Diagrammatic sketch of folding in northeast wall of west opening, Chapman quarry, as viewed from southwest side. Compare with Fig. 66.

The regularity of these jointing systems is well displayed in the photograph, Plate 53, B.

Though seeming more complex in structure, the geology of the east quarry is similar to that of the west opening and to the Chapman Standard quarry. The anticlinal axes are at depths of 30 and 100 feet. The same fold traces are seen in the southeast wall (see Fig. 68), as in the corresponding side of the west opening, though here not so readily pieced together because of the presence of irregular reentrants in the walls. At the surface on the northeast side of the hole, the beds strike N.70°E., dip 28°S., but about 40 feet below the surface the dip is vertical. The cleavage strikes approximately N.60-65°E., dips 15°S. Grain trends N.40-47°W., and is vertical.

Jointing is well marked. In addition to many lesser, irregularly curving, and generally iron-stained joints, called "scows" by the quarrymen, there is the same system of major joints striking $N.55-80^{\circ}E.$ and dipping vertically, and a set of fractures that strike $N.10^{\circ}W.-10^{\circ}E.$ dipping steeply. An unusual set of four joints strikes $N.35^{\circ}E.$, dips $75^{\circ}S.$ As in the opening to the west, many of the joints are coated with calcite.

A rather unusual feature is the presence of minor faulting parallel with the cleavage and apparently relieving the small folds. This is well shown in some of the rusty beds on an abandoned working level east of the present working level. A small fault, similar to those in the Jackson Bangor quarries and having a displacement of one foot, is seen in the southeast wall of the working level. The plane could not be measured, but it is clear that the beds beneath it moved forward, the fault in this respect again resembling those of the Jackson Bangor openings.

Production has been continuous since the opening of the quarry in 1850, but was severely reduced during the war, the cost of production having about doubled between 1914 and 1918.

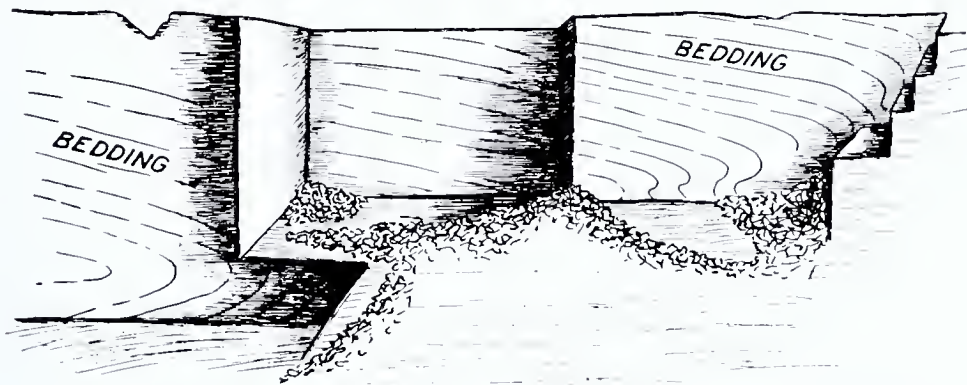


Fig. 68. Sketch of folding in southeast wall of east opening, Chapman quarry, as seen from northwest side.

The products include all sizes of roofing slate. A feature is the making of especially thick slate upon order; this slate, three quarters of an inch in thickness, is used to impart a rustic finish to residences designed to resemble old manor houses. The standard sizes of roofing slate produced vary up to 16 by 27 inches, with a thickness of 0.25 inch. Occasional orders are received for heavy flagging for garden walls. Grave vaults and fence posts also are made. About thirty years ago blackboards were produced, polishing being done with the aid of diamond dust.

7. *Keystone Quarry.* This opening is about 2,000 feet north of the station at Chapman and immediately west of the railroad. It is 270 by 325 feet in maximum dimensions and is said to be 250 feet deep, but is now filled with water.

The bedding could not be seen from the surface. The cleavage appears to strike $N.60^{\circ}E.$, and dips $20^{\circ}S.$ Several joints were seen striking $N.60-70^{\circ}E.$, dipping $70-90^{\circ}W.$; three of these form the northwest wall of the opening.

This quarry was opened about 1860 and operated until 1914.

8. A small cut in the hillside, about 400 feet N.65°E. from the Keystone quarry and east of the railroad, is 60 by 30 feet in area and has a maximum depth of 30 feet. In the south wall the cleavage strikes N.60-70°E., and dips 13°S. In the walls minor recumbent folds are visible, with axial planes striking N.70°E. and dipping 13°S.

9. *Wagner Quarry.* About due east of the Keystone quarry 1,000 feet, and east of the railroad is the Wagner quarry, a small cut 30 feet square and probably 25 feet deep. The bedding is not discernible; cleavage strikes N.70°E., dips 23°S. This opening was clearly only a prospect.

10.—11. *Fisher Nos. 1 and 2 Quarries.* These two quarries are about 300 feet apart. The south opening is 500 feet N.50°E. from the church in the town of Chapman. It is about 35 by 50 feet in size and 35 feet deep. The beds strike approximately N.65°E., dip 14°N., while the cleavage appears to strike parallel with the beds and dips 15°S. Grain trends N.35°W.

The larger opening is across the stream, northwest from the quarry just described. The depth is probably 60 feet. The beds strike N.75°E., and dip 15°N.; cleavage strikes about due east, dips 11°S. The grain trends N.50°W. Numerous joints are observed, falling into two sets, one striking N.0-15°E., dipping 50°E., the other striking N.65°E., dipping 70°S. These joint systems closely resemble those of the surface and deepest levels of the Chapman quarry. The two openings were shut down about 1880.

12.—13. *Lilly Nos. 1 and 2 Quarries.* These two openings are 300 feet apart and in the valley of the east fork of the small stream that flows through the Chapman quarry. Both are small, the northerly being 60 feet square, the other 100 by 25 feet in size. No great depths were reached. The north opening shows no slate above the water, but the southern hole exposes bed rock near the north corner. Here the beds strike N.67°E., dip 37°N.; cleavage strikes N.78°E., dips 10°S. The grain trends N.33°W. Prominent joints strike N.70°E., and are vertical.

The slate produced is typical of the hard belt. That seen on the dump has somewhat fewer "ribbons" than usual, and good cleavage, but bears closely spaced, calcite-filled joints. The quarries were abandoned in 1875 or earlier.

14. *Fisher No. 3 Quarry.* This small opening lies at the fork of the little creek that flows through the Chapman quarry. It is 50 by 40 feet in size and probably 20 feet deep. Water now fills the quarry. No slate is seen in place. The quarry was abandoned about 45 years ago.

15. This old, long abandoned opening is just east of the railroad and ½ mile north of the Chapman station. It is 200 by 30 feet in size. The depth is not known. No slate is seen above the level of the water which fills the hole.

16. *Mauch Chunk Quarry.* Directly east of the station at Chapman, on the east side of Monacaey Creek, is a quarry about 250 feet square. This old opening has an extensive dump to the south but no

slate is seen in place. Sanders¹ gives the dip as vertical, the cleavage as striking N.50°E., dipping 22°S. At depth the cleavage is said to have been irregular.

Operations ceased before 1878, for Sanders speaks of the quarry as abandoned.

17. *Chapman Superior Quarry.* This moderately large hole lies N.80° E., 5,000 feet from the Chapman quarry, and about 3,000 feet N.40° E. from the Siegfried school, in a valley that leads to the east branch of Monocacy Creek. The opening is 150 feet square, and is said to be 125 feet deep. Water now fills it. The beds appear to dip gently north, and the cleavage strikes approximately due east, dips 20°S. The quarry was shut down in 1911.

18. *Ed Smith Quarry.* The Ed Smith quarry is a small opening, about 40 feet square, 1,200 feet east of the Siegfried school. It is filled with water. A little "ribboned" slate forms a dump on the northeast side but no rock is seen in place. This is clearly only a prospect.

19. *Hagenbusch Quarry.* In the valley of the east branch of the Monocacy, about 1½ miles east of the Warren school, is the old Hagenbusch quarry. It is 90 by 40 feet in areal dimensions and about 50 feet deep. No slate shows above the water with which the quarry is filled, but the dump on the southeast side bears blocks of closely "ribboned" hard slate, not heavily rusted nor unduly decayed. Quartz veinlets and a little pyrite are seen in some of the blocks.

20. *Turner Quarry.* The Turner quarry is in the stream bottom, 1,000 feet south of the Reading quarry. It is 60 by 80 feet in size. The depth is not known, but is probably at least 60 feet. A little slate shows above the water, but the bedding is not recognizable; the cleavage strikes N.70°W., dips 15°S.

The slate on the dump is rusted on the "ribbons". The beds are somewhat thicker than is usual in the hard belt. The opening has long been abandoned.

21. *Reading Quarry.* The Reading quarry is 600 feet downstream from the Hagenbusch quarry and occupies the southeast angle at a road intersection 1½ miles east of the Chapman quarry. It is estimated to be 60 feet deep. In ground plan it is triangular, and about 150 feet long on each side.

In the northeast wall the cleavage strikes N.80°E., dips 30°S.; bedding strikes N.85°W., dips 12°S. The bedding dip in the bottom is said to steepen to 30°. Several joints striking N.85°E. and vertical are conspicuous in the walls. The slate on the dump is of good quality. This quarry was operated at intervals up to 1893.

22. *Magee Quarry.* This is the western of two openings that are immediately northeast of the highway three-quarters of a mile N.60°E. from Dannersville, and half a mile northwest of the Steekel quarries. It measures about 70 by 85 feet and is irregular in outline. The probable depth is 50 feet.

Typical hard slate is exposed. The beds strike N.35°E., dip 28°S.

¹ Sanders, R. H., op. cit., p. 104, 1883.

Cleavage strikes N.70°E., dips 15°S. Grain trends N.45°W. Conspicuous vertical joints strike N.75-80°E.

The quarry was opened in 1866 and abandoned in 1872. The product was roofing slate.

23. *Rippon and Wolle Quarry.* This lies 150 feet east of the Magee quarry and directly across the stream. It is a subcircular hole, about 60 feet in diameter and having a depth of 40 feet. The beds, some of which are here as much as 6 inches thick, curve around the axis of an anticline, overturned northward; the axial plane dips 15°S. The cleavage strikes N.75°E., dips 7°S. The grain trends N.40°W. Two northeast-striking, vertical joints are seen.

The quarry was opened in 1885. Several thousand squares of good slate were produced, but operations ceased long ago.

24. *Schlegel Quarry.* A small opening is on the south side of the road, east of the Schlegel house, and south of the Magee quarry, on the property of Mr. W. H. Schlegel. No slate is seen on the place, the pit being filled with water.

25.—26. *Steckel No. 1 and No. 2 Quarries.* Immediately east of the road 2 miles northwest from Bath on one of the small headwaters of the Monocacy, are two quarries only 20 feet apart. The northern is irregular in shape, with maximum dimensions of 110 by 115 feet. Only about 8 feet of rock are visible above water level. The dump is between the road and the opening. The slate is typical hard slate. The beds strike N.35°E., dip 57°N., and the cleavage strike is N.55°E., the dip 11°S. The grain trends N.30-37°W.

The southern opening is rectangular, 100 by 110 feet in size. Here, beneath a maximum overburden of a foot of weathered slate, the beds strike N.35°E., but dip southeast, apparently being south of an emerging synclinal axis of which the axial plane dips south about 11°.

These quarries have not been operated since 1870.

27. *Dick Quarry.* The Dick quarry is a small opening about 1½ miles north of Bath, on the road leading to the Steckel quarries (Nos. 25 and 26), and east of the stream. It is about 20 by 30 feet in size and 15 feet deep at most. A little slate shows in the northeast wall. This prospect was opened about 40 years ago.

28. Approximately 1,800 feet south of the station at Chapman, just west of the railroad and in the valley of Monocacy Creek, is an old quarry. It is about 150 by 60 feet in ground plan. The depth is at least 50 feet, but water now fills the opening.

Near the north corner typically "ribboned" hard slate is exposed, the beds striking N.55°E., and dipping 65°S., whereas the cleavage strikes N.60°E., dips 13°S. Grain trends N.33°W., dips 75°W. The opening is on the upper limb of a northward overturned anticline. The quarry was abandoned at least 50 years ago.

29. *Rhymer Quarry.* This is a prospect, 20 by 30 feet in area and about 15 feet deep, 1¼ miles NW. of the Bath railroad station. It is situated in the bed of Monocacy Creek and is filled with water. In the bottom of the stream nearby the slate strikes N.50°E., dips 60°S., and cleavage strikes N.63°E., dipping 20°S. The opening was made about 1895.

30. About 600 feet due north of the Roth quarry, in the valley of a small stream, is a cut about 35 by 35 feet and probably 25 feet deep. The bedding is not recognizable, but the cleavage dips gently south and the grain trends N.53W. This opening, abandoned 50 years ago, yielded roofing slate for nearby houses.

31. *Roth Quarry.* About one mile N.70°W. of the Bath railroad station is a schoolhouse, approached by a road leading westward. Some 800 feet east of this school is a small opening lying south of the road. It is 40 by 15 feet in ground plan, and 25 feet deep to water level. About 10 feet above the water is a cleavage slip plane, partially filled with quartz and calcite. Good slate probably came from this opening. Operations ceased about 50 years ago.

32. *Achenbach Quarry.* This is located about one mile north of Bath, on the Chapman road. It is a roughly rectangular opening, measuring 70 by 160 feet in ground plan, between the road and Monocacy Creek. Its depth is about 45 feet but no slate occurs in place above water level.

The slate quarried was of a fair grade, but core drilling revealed "crooked" cleavage at depths of 13, 38, and 60 feet, the cleavage planes being warped. These observations, made by Prof. B. L. Miller, of Lehigh University, suggest the presence of cleavage slips in the openings, similar to those seen at the Belfast and Edelman quarries.

The quarry was operated from 1914 until about 1916, producing roughly 230 squares of roofing slate in 1914, the only year for which figures are available. It is now abandoned and no machinery remains.

33. *Fleischman Quarry.* This small opening, 60 by 40 feet and about 60 feet deep, is on the west bank of the stream, 300 feet west of the Daniels quarry.

The beds appear to strike N.70°E., dip 17°S., but are not clearly shown. The cleavage on the west wall is curved; it strikes N.70°E., dips generally 8°S. The strata are thus on the north limb of a northward overturned antiline.

The slaty cleavage is exceedingly rough and irregular, and false cleavage, striking parallel with the slaty cleavage and dipping vertically, is seen. The grain trends N.37°W., and is vertical. Several well-marked joints strike N.65-75°E., dip vertically. This quarry was last operated about 1910.

34. *Daniels Quarry.* The Daniels quarry is about $\frac{3}{4}$ mile N.60°E. from the Penn Allen Cement Company plant, between Bath and Nazareth. It measures 70 by 225 feet; 20 feet of slate show above water level and the opening is estimated to be 60 feet deep. The slate chips on the dump have a good ring and do not "rust" heavily. The bedding is not clearly visible, but there is some suggestion of close folding in the walls. The cleavage strikes N.65°E., dips 11°S. Slate was quarried here as late as in 1878. More recently the quarry has been used as a reservoir by the Dexter Cement Company, which owns the land.

35. *Bader Quarry.* The quarry is situated about seven-tenths of a mile south of the Warren school. Only the dump is still to be seen,

the quarry being filled. A little slate outcrops along the stream nearby, striking N.80°W., dipping 20°N.; the cleavage strikes N.15°E., dips 15°S. Typical "ribboned" material is seen on the dump. The opening was abandoned in 1900.

36. *Roon Quarry.* The old Roon quarry is about 1½ miles southwest of the Mill Grove school in the stream valley, not far from the tracks of the Nazareth branch of the Lehigh & New England Railroad. It is rectangular, 105 by 45 feet, and probably about 60 feet deep.

The typical hard slate beds strike N.58°E., dip 4°S., whereas the cleavage strikes N.65°E., dips 15°S. Grain trends N.35°W. Conspicuous vertical joints seen in the south wall strike N.50°E.

37. *Hayer Quarry.* This opening lies 1,500 feet east of that last described. It is virtually rectangular, small, and probably about 70 feet deep. Some 15 feet of slate are visible above water level on the northwest side.

The slate exposed is typically "ribboned" hard slate. In the south corner the beds strike N.10°E., dip 37°N., whereas the cleavage strikes N.60°E., dips 18°S., and the grain trends N.38°W. The structure is thus the south limb of a northward overturned anticline pitching westward. The joints observed strike N.55°E., dip 60°S. The slate has curly cleavage; the material on the dump rings well. The quarry was last operated about 1915, and probably was opened 5 years earlier.

38. About three-quarters of a mile down the Bushkill from the Center school and about 2.5 miles directly south of Knechts, on the east side of the creek and road, is a large opening in the hard slate. It measures 250 feet by 100 feet. Its depth is not known but is probably at least 75 feet. No slate shows above water level.

SEEMSVILLE GROUP.

The quarries of the Seemsville group are opened along Catasauqua Creek, east and south of Seemsville. Slate produced could best be shipped through Bath and from that town, also, supplies and labor would normally be obtained when the quarries were being operated.

The beds opened are in the lower part of the hard belt, the lowest subdivision of the Martinsburg. The rock is typical of this member though in a few of the openings the "ribbons" must have been unusually thick. The quarries are so largely filled with water that structural determinations are difficult, but the usual close folding of thinly bedded slate is in evidence. Bedding and cleavage strikes are generally N.60-70°E., but in some quarries, such as the Miller opening, they assume a northwest direction. Most of the prominent joints have a northeast strike.

Of these openings, the Koch, Ziegenfuss, and Miller quarries represent fairly extensive operations. All have been abandoned for the last 20 years. The products were mainly roofing slate, with smaller values of slabs, fence posts, and grave vaults.

1. *Koch Quarry.* This large opening, 250 by 100 feet in size, is just north of the road where the latter crosses Catasauqua Creek, three-quarters of a mile southeast of Seemsville. The estimated depth is about 100 feet, but the opening is now so full of water that only on

the north side, where the wall rises 30 feet above the water level, can slate be studied. Here the bedding strikes N.55-60°E., dips 17°N.; the cleavage is horizontal. Grain trends N.47°W., and is vertical. One joint, striking N.58°E. and dipping 40°S., is in the northwest wall of the opening. Seven other well-marked joint planes are observed to strike N.70-80°E., with dips of 70-90°S.

The beds in which the quarry is cut are probably approximately the same as at the Ziegenfuss quarry (Number 3. below).

The quarry was already abandoned in 1878, at the time of Sanders' survey.¹

2. On the west bank of Catasaqua Creek, 1½ miles north of where it is crossed by the Weaverville-Howertown pike, is a small hole, apparently a long abandoned quarry. No slate is visible, however, above water level.

3. *Ziegenfuss Quarry.* This irregularly shaped opening is 1,000 feet N.50°E. from the Koch quarry. It is about 120 feet square but very irregular in shape. The depth is said to be 100 feet, but the opening is largely filled with water.

The beds are typical hard slate, fairly free of "ribbons." No rusting is seen, nor any quartz or calcite, except as mentioned below. The slate quarried appears to have been of high quality. The bedding is only faintly indicated, and there is a suggestion of a gentle southeast dip, probably on the lower limb of a northward overturned anticline with horizontal axial plane.

Cleavage strikes N.35-75°W., dips 6-10°S., but these observations are poor. It is curved locally, proving its deformation after development. The grain strikes N.38-55°W., and stands vertical. The joints are irregular and in a measure determine the form of the opening. A striking feature is a quartz stringer which runs in a plane parallel with the cleavage along the entire northeast wall of the opening.

The quarry was operated until about 30 years ago, when it became difficult to obtain laborers.

4—5. These two small prospect pits in hard slate are on the south bank of the east fork of Catasaqua Creek, about 1,500 feet east of the Ziegenfuss quarry. No bed rock can be seen.

6. *Miller Quarry.* This opening is 400 feet south of the road, opposite the Miller No. 2 pit and in the same valley. It is trapezoidal in form and measures 220 by 270 feet. A slight thickness of slate shows in the walls, but water conceals the true depth.

The beds strike N.65°W., dip 35-75°S., the dip increasing southward. The cleavage has a similar strike, dips 15°S. Prominent joints in the east corner strike N.80°E., dip 67°N.

The slate seen on the dump has a good ring, closely spaced "ribbons," and a somewhat sandy texture for the most part. Surfaces of blocks show papery exfoliation.

This is known as the Miller quarry. It was operated in 1878², and abandoned about 35 years ago.

7. *Miller No. 2 Quarry.* One mile due south of Dammersville one

¹ Sanders, R. H., op. cit., p. 107.

² Sanders, R. H., op. cit., p. 106.

of the headwaters of Catasauqua Creek is crossed by a road leading northwest. About 300 feet north of this road and in the stream valley is a rectangular opening 40 by 30 feet in size, estimated to be 40 feet deep. The slate on the dump and in the walls shows good cleavage, but weathers readily and exfoliates so as to give a papery effect. This hole was opened 50 years ago and was worked chiefly to furnish pulverized material for paint. It has long been abandoned.

QUARRIES IN WESTERN PART OF DISTRICT

SLATINGTON GROUP.

The quarries in this group occupy an area the longer extent of which is northeastward, passing from Slatedale in Lehigh County and west of the Lehigh River eastward through Slatington, Walnutport, Berlinsville, and Danielsville. Slatington, with a population of about 4000, is the dominant town of the district; the quarries farthest away from it—those at Danielsville—are at most seven miles distant. All quarry operations have rail connections with Slatington by the Lehigh Valley, Reading or Lehigh & New England railroads.

The quarries of the Slatington group are opened in the soft slate or upper member of the Martinsburg formation and in the same beds as those of the Bangor, Pen Argyl, and Slatefield groups of the eastern part of this district. The larger divisions of the sequence and the uses to which the slate beds are put have been given on pages 186-190. It has been pointed out (pages 190-192) that by means of the Gray beds between the Franklin and Star "runs" in the Danielsville region, a tentative correlation with the Pen Argyl and Bangor beds appears to be justified.

In structure the Slatington region differs from the Bangor-Pen Argyl region in that the folds have axes that are more nearly vertical, so that individual beds are brought to the surface on both sides of the axis. In some sections transverse to the regional strike, beds are repeated not once only, but again and again; the result is a complex outcrop pattern suggesting, though on a far smaller scale of course, that of the Appalachian Valley. The number of fold axes, too, is far greater than recognized at Bangor and Pen Argyl. In a section along Lehigh River between the first slate outcrops at Slatington and Lehigh Gap, twelve anticlinal axes and eleven synclinal ones are recognized and there are certainly several more which are not exposed. The most prominent and persistent of these are the Prudential, Empire, Cambridge and Eureka synclines which are exposed in or near the quarries after which they are named. The Prudential and Eureka synclines extend completely across the Slatington region.

Further details of the structures in the Slatington region can best be derived from the large-scale geologic map (Plate 54) and the structure sections (Plate 55, 56). By using solid lines to indicate axes and key beds, where these are known to occur with certainty or inferred to be present with a high degree of probability, and broken lines elsewhere, an attempt is made to distinguish for the reader's benefit between virtual certainty and mere probability. Naturally this distinction may not be pressed too far. Knowing the thickness between beds, even in structures as complexly folded as these, the probable outcrop of definite horizons may be inferred with a fair degree of

certainty. At the other extreme, however, when inference approaches the outer fringes of probability, even a mere likelihood, when it exists in the mind of a geologist acquainted with the regional structure, merits recording for the benefit of the layman or newcomer. Most of the dashed lines indicate axes or outcrop-lines intermediate between these two extremes. Particular uncertainty obtains where beds are mapped at the ends of pitching axes, for such pitches, as noted below, vary in direction and degree from place to place along the axis; a dip must therefore be assumed, and doubt is thus cast upon the projected bedding traces. This is especially true of the outcrop of the Franklin bed in the valley of Lehigh River north of Slatington; the statement also applies to the region between the outcrops mentioned and App.

Most of the folds show a tendency to northward overturning, but this feature is not nearly as well marked as farther east,—for example, in the Old Bangor syncline (see pages 214-216) at Bangor.

It may also be seen, from the “canoe-shaped” bedding traces, that there is a definite pitch to each of the folds in the region. This pitch of the fold axes is not uniformly in any one direction, nor does it show steep angles. The steepest axial pitch recorded is 15° , at the Empire quarry. At the Old Cambridge quarry the axis of the Cambridge syncline pitches west 4° , but the pitch probably changes to eastward at the west edge of the Blue Ridge quarry, to judge by thickness measurements. Again, the Eureka syncline pitches west at the Eureka, Mountain, and Pittston quarries, but at the Locke and nearby quarries in Slatedale it pitches gently east and on its westward continuation at the Blumont quarries, between Slatedale and Lehigh Furnace, the pitch is west again. The Prudential syncline pitches west near the Highland quarries (southwest of Slatedale), but 5° east in the Blue Mountain Slate Company's quarry, southeast of Slatedale.

As already noted, the dip of the cleavage planes is steeper here than at Pen Argyl and Bangor. Moreover, it distinctly radiates upward at the crests of anticlines, and downward at synclinal troughs. Cleavage strike is slightly more easterly than in the regions farther east, averaging exactly $N.70^{\circ}E.$ in 50 observations selected at random from Slatington quarries, as compared with $66^{\circ}E.$ for a random selection of 50 quarries at Pen Argyl and Bangor. With this goes a more northerly bearing of the grain, which may be generalized as striking about $N.30-35^{\circ}W.$ (see Figure 69) instead of the $N.45^{\circ}W.$ trend observed near Pen Argyl and Bangor; this change is consistent with the observation that the opening angle between the strikes of cleavage and grain approximates 90° .

False cleavage is far more prominent here than in the eastern part of the Lehigh-Northampton district. It is especially well developed near the axes of folds. Thus, it shows in the Blue Mountain quarries southeast of Slatedale, near the bottom of the Prudential syncline, and again in the Custer quarry, located on the first anticlinal crest south of the Empire syncline. On the other hand, its conspicuous development in the Hower quarry at Danielsville, apparently well away from fold axes, is not readily explicable. In those cases where seen in place, the false cleavage planes are parallel to the fold axes, as well as to the axes of minute “crumpled” folds of the cleavage.

True faulting of importance was nowhere observed in the Slatington

PLATE 55.

Structure sections in Slatington district at Danielsville and Berlinsville; see Plate 54 for lines of sections;
scale 1:31250 (1 inch=1½ mile).

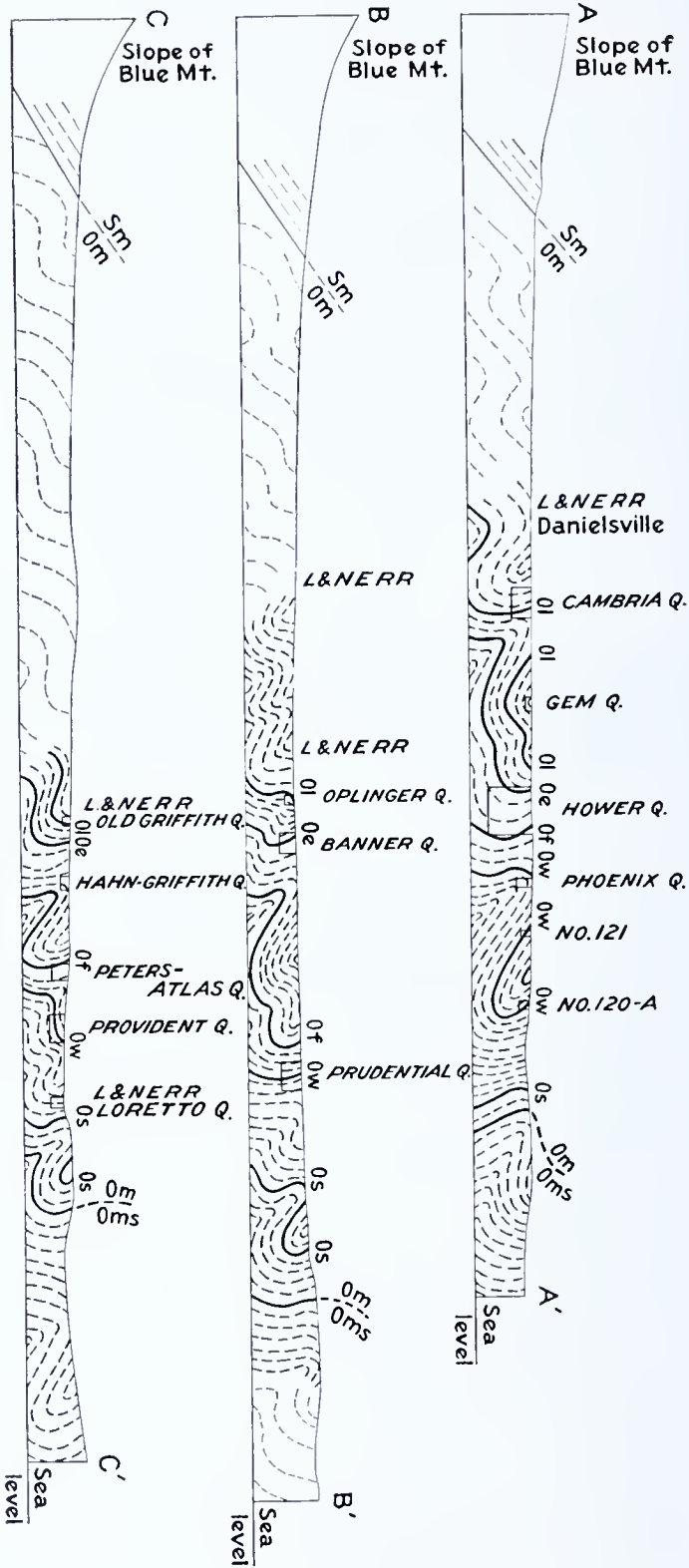
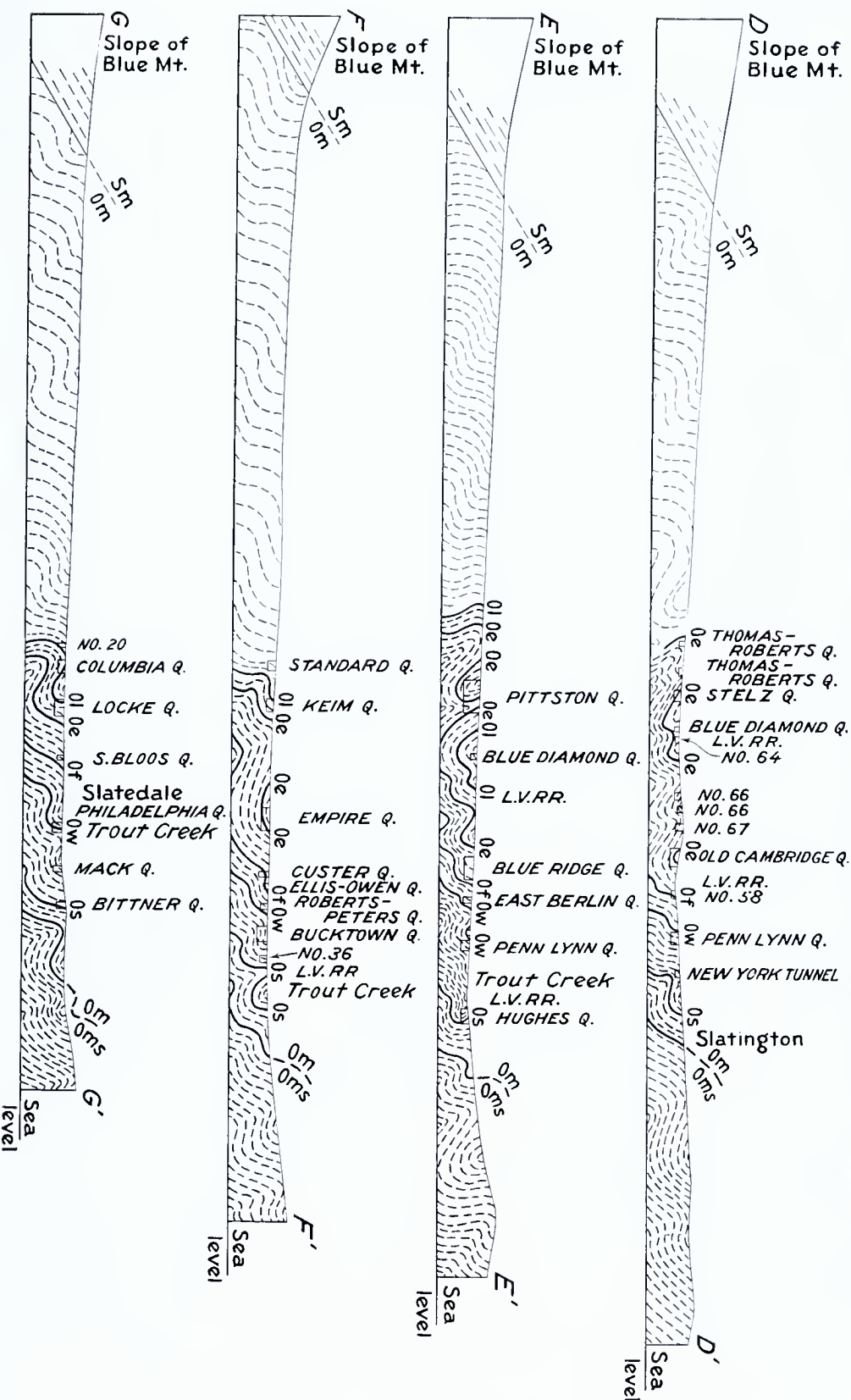


PLATE 56.



Structure sections in Slatington district at Slatington and Slatedale; see Plate 54 for lines of sections;
 Scale 1:31250 (1 inch = 1½ mile).

region, but what appears to be a bedding-slip is seen in the Empire quarry (see page 296).

The most conspicuous system of jointing, as in the Bangor and Pen Argyl regions, is approximately parallel in strike to the strikes of bedding and cleavage, but dips variously.

One outstanding difference between the quarries of the Slatington group and those at Pen Argyl and Bangor is that the former aim to follow individual well-recognized and large beds, the quarried blocks of more thinly banded material being regarded almost wholly as waste; as a consequence very little "ribboned" roofing slate is produced. In general, however, the products do not differ from those of the Pen Argyl and Bangor regions. There is no pulverizing plant anywhere in the Slatington group, and marbleized slate also is not made. On the other hand, school slate is important and the Slatington region produces more school slate than any other in the United States,—is in fact the only school slate district of importance in this country.

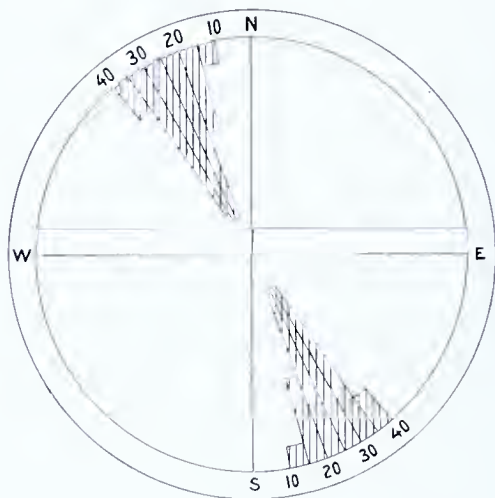


Fig. 69. Azimuth chart of strike of grain in 31 quarries at Slatington. The numbers indicate degrees in azimuth west of north (east of south) in bearing of grain strikes. The relative lengths of the inward extending lines show the relative numbers of observations yielding the indicated strikes.

Two of the Slatington quarries operating in 1927 were actual mines, while four others cut well into the quarry walls and thus virtually constitute tunnelling operations. Although none of the quarries of the Slatington group rivals the Albion, Old Bangor, or Consolidated-Star in areal dimensions, several are of conspicuous size, the Blue Valley east of Rextown being the largest single quarry. It is noticeable, however, that many are small surface openings developed along the strike of individual beds and thus resembling some of the narrow but generally longer quarries at Monson, Maine¹.

In 1927, when the last careful study was made of the quarries of the Slatington group, twenty-one were being actively operated.

On the small-scale map (Plate 25) showing the western part of the Lehigh-Northampton district, the individual quarry holes can in

¹ Dale, T. N., *Slate in the United States*; U. S. Geol. Survey Bull. 586, pp. 78, 79, 1914; Bowles, Oliver, *The technology of slate*; U. S. Bur. Mines Bull. 218, p. 39, 1922.

many cases not be shown separately because so small and so closely spaced. In such cases several openings are indicated by a single quarry mark and quarry number. For a more accurate impression of the number, location, and size, the reader is referred to the large-scale map of the Slatington region; in preparing this, the quarry locations and sizes were surveyed with an alidade and are accurate within 100 feet. In the quarry descriptions of the text, where, because of close spacing, a single number has been used to designate a group of quarries, supplementary letters have been given to distinguish individual openings within the group.

1. *Old Diamond Quarry.* This irregular-shaped opening shows about 35 feet of slate above water level on its east side. The quarry is north of and probably near the crest of a northward overturned anticline; the strike of the bedding is $N.70^{\circ}E.$, and the dip $18^{\circ}N.$, and the beds are flattening in a northward direction as they approach the Prudential syncline. The strata exposed are the two Williamstown (here generally called "Saegersville") big beds. Cleavage strikes parallel to the beds and dips steeply south.

This opening has been shut down for about 25 years.

2. *New Diamond Quarry.* The quarry measures 140 by 70 feet and exposes 40 feet of slate above water level. The structure and beds are as in the Old Diamond quarry, except that the strata dip $45^{\circ}N.$ —more steeply than at the latter; the quarry is thus seen to be structurally slightly farther south, as well as topographically higher, and thus yet closer to the crest of the anticline mentioned in the description of the Old Diamond quarry. Grain trends $N.24^{\circ}W.$ The quarry has been long abandoned, but was worked more recently than the Old Diamond.

3. This unnamed opening measures about 60 by 100 feet and is approximately 80 feet deep. In it the beds are seen to dip $83^{\circ}N.$ and strike $N.72^{\circ}E.$ It thus lies virtually at the crest of the anticline mentioned above. Cleavage strikes parallel to bedding and dips $83^{\circ}N.$; grain trends $N.21^{\circ}W.$ The beds exposed are again the two Williamstown big beds. The quarry has been abandoned for some time.

4. These three small, long-abandoned prospects show no slate in place. They are on the south limb of an anticline, as the beds in the nearby stream strike $N.65^{\circ}E.$, dip $20^{\circ}S.$, while the cleavage dips more steeply in that direction. No big beds are known to be exposed.

5. *Peach Bottom Quarry.* This opening is small, measuring 80 by 55 feet. In it two big beds are exposed; the upper (or north) one is $13\frac{1}{2}$ feet in actual thickness and is separated by $13\frac{1}{2}$ feet of "rib-boned" slate from the lower (or south) bed, which is $10\frac{1}{2}$ feet thick. This sequence constitutes the Peach Bottom "run," which is at the base of the upper Martinsburg member, as mapped. This is the only quarry in the Slatington region in which this "run" can now be studied. It probably corresponds to the Grand Central "run" at Bangor.

Cleavage strikes $N.75^{\circ}E.$, dips $50^{\circ}S.$; grain trends $N.12^{\circ}W.$

The quarry has long been abandoned.

6. *West Highland Quarries.* These two small openings measure



A. Looking east across Locke beds from Quarry 18 a; dump and mill of Royal Blue quarry in right distance. Lower (First) Locke big bed shows a little north of the right hand corner of the quarry.



B. Eastmost Highland quarry, middle of southwest wall, to show flattening of beds in small syncline. The Upper Williamstown big bed is the lowest big bed in this view.

about 60 feet each on the side and each is about 100 feet deep to water level. Both expose the two Williamstown big beds, which strike $N.68^{\circ}E.$ and dip $85^{\circ}N.$ at the surface. The cleavage dips $65^{\circ}S.$; grain trends $N.33^{\circ}W.$ These quarries were once operated by the Highland Slate Company but are now owned by the Vendor Slate Company and are not being worked at present.

7. *Highland Quarries.* This group consists of four small openings, none of which measures more than 100 feet on a side except the eastmost, which is somewhat larger (90 by 130 feet). The depth in no case exceeds 75 feet.

The beds opened are the Williamstown big beds, which, in the three westmost quarries, strike $N.70^{\circ}E.$, dip $22^{\circ}N.$ at the surface but $75^{\circ}N.$ at depth (evidently just south of the trough of the Prudential syncline), whereas the cleavage strikes $N.70^{\circ}E.$, and dips $66^{\circ}S.$ The eastmost and somewhat larger opening shows the west pitch of this structure in the flat trough of the syncline which is exposed near the middle of the hole (see Plate 57, B). In all four openings the cleavage strikes $N.70^{\circ}E.$, dips $60^{\circ}S.$; grain trends $N.37^{\circ}W.$

These quarries were operated by separate companies, the three westerly ones constituting one unit and the eastmost another. They are now abandoned.

8. *Blumont Quarries.* Two irregular openings lie about half a mile east of Lehigh Furnace, on the property of G. T. Eberwein of Slatedale. Each is about 110 by 225 feet in area and shows 20 feet of slate above water level but both are probably much deeper. They show beds striking about $N.40^{\circ}E.$ and dipping $40^{\circ}N.$ on the southeast edge of the west opening, but flattening to an almost horizontal position at the north edge of the east opening. They are thus on a synclinal axis thought to represent the westerly extension of the Eureka syncline, and the structure pitches west, as the cleavage has a more easterly strike ($N.72^{\circ}E.$). The beds could not be correlated with certainty, but are described by quarrymen as resembling in details of sequence those of the quarries just west of the Manhattan; hence they are probably higher than the Upper Locke (Manhattan) big bed and are in the Columbia "run." One big bed, about 20 feet thick, is seen in the east corner of the east opening. Cleavage strikes $N.72^{\circ}E.$, and dips $50^{\circ}S.$

This group of quarries was first opened in 1904 and shut down in 1927. Electrical and structural material were produced and, up to 1915, roofing slate as well. Nearby is a well-equipped mill.

9. *Saegersville and Hope Quarries.* This is a group of five openings west of the road from Peters Store to Lehigh Furnace, and about 2500 feet southeast of the Lehigh Furnace schoolhouse. The one farthest west is small and shows no big beds. East of it are three other small holes, the two easterly of which are in the Peach Bottom beds. These four openings are referred to as the Saegersville quarries.

About 200 feet farther north is a larger quarry, generally called the Hope; this measures 535 by 90 feet. It is opened along the strike of the Williamstown big beds. In it the beds strike $N.72^{\circ}E.$, and dip $77^{\circ}S.$; as the cleavage dips more gently, this opening lies on the south limb of a syncline, thought to be the Star syncline.

The Hope quarry was worked thirty or more years ago. The Saegersville quarries were opened even earlier and shut down about 1900.

10. *Fenstermacher and Roth Quarry.* This small irregular opening, 40 feet deep, but now filled with water, is situated about 400 feet northeast of the Hope quarry and shows no slate in place. It is said to have been opened in the Blue Mountain "run." It has long been abandoned.

11. *East Saegersville Quarries.* This group, mapped as four openings on the small-scale map, actually consists of six quarries (see Plate 54) of which the middle two are very small. All lie along the strike and outcrop of the Saegersville big beds. The two smaller openings exposed only a part of the Saegersville "run." The four larger quarries are rectangular, about 60 feet wide, and varying in length (which is parallel to the strike of the beds) up to 265 feet and in depth to 100 feet.

The bedding strikes uniformly $N.75^{\circ}E.$ and dips steeply ($75-87^{\circ}$) north. Cleavage strikes about $N.75^{\circ}E.$ and dips $45^{\circ}S.$ The grain trends about $N.30^{\circ}W.$ Prominent joints are lacking.

The entire production of these quarries was from the Williamstown "run." The group has been abandoned for some time. A property line separates the easternmost from the other openings of this group.

12. These four openings, each about 400 feet from its neighbors, are developed along the strike of the Blue Mountain "run" and lie about 1300 feet south of the Slatedale post office, on the south side of Trout Creek valley. In order, from west to east, they measure 70 by 70 feet, 130 by 150 feet, 90 by 250 feet, and 40 by 80 feet, being uniformly longest in the direction of the strike. The maximum depth seen (that in the middle openings) is 40 feet, but all are water-filled and probably somewhat deeper.

The three easterly openings expose the upper Blue Mountain big bed near their northwest sides. The strike is $N.70-75^{\circ}E.$ and the dip $80^{\circ}N.$ at the surface, steepening downward. The cleavage strikes about $N.70^{\circ}E.$, dips about $52^{\circ}S.$; structurally, therefore, these quarries are south of a synclinal axis,—the Empire syncline. Grain trends $N.22^{\circ}W.$

These quarries have all been abandoned for at least fifteen years.

13. *Philadelphia Quarry.* This long abandoned opening measures 125 by 175 feet and is 30 feet deep, but is now filled with water. No slate can be seen in place now. It is said to have been opened in the Washington "run," the beds standing vertical.

14. *Bittner Quarries.* These ten small quarries are narrow, deep openings, close together along the strike and outcrop of the Williamstown "run." In width (transverse to the strike) they range from 60 to 110 feet, and in length up to 110 feet. The depths are 215 feet or less. Separate holes are in part connected by tunnels through the adjacent walls.

The strata worked are the two big beds of the Williamstown "run." The upper big bed is 8 feet, the lower 15 feet thick in this quarry. They strike $N.80^{\circ}E.$, and dip 70° to $85^{\circ}N.$ The cleavage strikes similarly but dips about $50^{\circ}S.$ The exposures in this line of quarries are clearly

a very short distance north of the crest of an anticline. Grain trends N.37°W., and is vertical. A series of joints parallel in strike to the beds, but dipping very gently (15-20°) north is well developed.

These quarries have had a highly varied history, beginning about 1900; in 1927 two of the openings were being worked by the Manhattan Slate Company.

15. This isolated opening, 70 by 65 feet in area, lies 100 feet north of the Bittner quarries. In the middle of the northeast side it exposes a bed about 11 feet thick. This and another, more northerly (higher) big bed, not here visible, are said to lie between the Blue Mountain "run" and the Williamstown "run" and are locally known as the Kuntz "run." The strata strike N.72°E. and dip 87°N.; cleavage strikes N.80°E., and dips 55°S.

Operations here have been long discontinued.

16. *Mack Quarries.* These seven small openings, none measuring more than 75 feet deep, lie along the strike of the Blue Mountain run, north of Quarry 15. The beds strike N.70°E., with dips of 70-80°N.,—evidently, like the Bittner quarries, still on the south limb of the Empire syncline, for the cleavage strikes N.78°E. and dips 55°S. The western pit exposes both big beds of the Blue Mountain "run," the upper being 15, the lower 11 feet thick, and the two separated by 5 feet of "ribbons."

Part of the operations here were carried on by means of tunnels from one opening to the next. The quarrying was done about the year 1900 by L. Mack & Company. Good roofing slate was produced.

About 300 feet north of the eastern one of the Mack quarries, in the steep cliffs on the south bank of Trout Creek, a small quarry exposes the trough of the Empire syncline, here closely folded and pitching 6°NE.

17. Three old openings are situated in a line along the regional strike 200 feet south of Trout Creek. The western one is largest, measuring 50 by 110 feet. None shows over 30 feet of slate above water level. The two big beds seen in these quarries are in the Trout Creek "run." They strike N.75°E. and dip 75-87°N. Cleavage strike is parallel and the dip is 58°S. Grain trends N.20°W. and is vertical.

These openings have long been abandoned.

18. Four abandoned quarries here lie close together, three of them (*b*, *c*, and *d*) forming a line trending N.60°E. and the fourth (*a*) being about 150 feet south of the middle one. All are situated about half a mile N.50°E. of the Lehigh Furnace school.

The southern (Quarry *a*) measures 165 by 240 feet at the surface and is at least 100 feet deep, with a tunnel in the northwest wall. The beds exposed include two thick strata, the Middle and Lower Locke big beds, which are also seen in quarries to the east. The Middle Locke bed is 10 feet thick, and separated by 46 feet of thinner beds from the Lower Locke bed, which is 14½ feet in actual thickness. The strata strike N.72°E.; they dip 81°S. at surface but flatten northward and downward, approaching the Eureka syncline. The cleavage strikes N.72°E. and dips 56°S. (see plate 57, A).

The other three openings are all narrow, the middle one being 385

feet long and the other two much shorter. They are in the Upper Locke (Manhattan) big bed. The strata here strike $N.65^{\circ}E.$ and dip $85^{\circ}N.$, whereas the cleavage strikes $N.72^{\circ}E.$, and dips $62^{\circ}S.$

All of these openings have been long abandoned.

19. *Columbia Quarry.* This lies about 250 feet north of those last described. The maximum depth is probably 90 feet, but water rises to within 60 feet of the ground. At the surface along the southeast edge, the dip is $10^{\circ}N.$, whereas it is $82^{\circ}N.$ along the northwest edge,—in short, there is a sharp anticlinal fold, the axis of which outcrops a little south of the northwest edge of the opening, and a syncline occurs between this and the No. 21 or Locke quarry (see Figure 70). Cleavage strikes $N.70^{\circ}E.$ and dips $45^{\circ}S.$

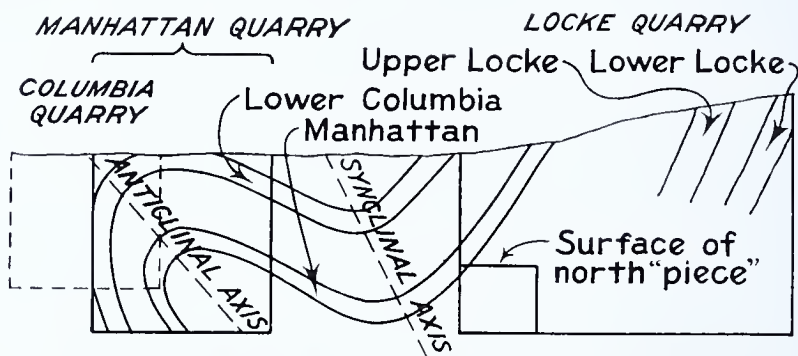


Fig. 70. Section transverse to strike across Locke and Manhattan quarries at Slatedale, to show structure of the big beds. Bed labelled Upper Locke is Middle Locke of this report.

The beds in this quarry lie immediately above the Upper Locke or Manhattan big bed and constitute the Columbia “run”. The lower Columbia big bed shows in the middle of the southwest wall. A second big bed, separated from the last by 50 feet of “ribbons” comes to the surface near the northwest edge. This upper bed bears at its south end a conspicuous gray-green, carbon free layer about 9 inches thick, resembling but believed to be higher in the sequence than the “Gray” bed seen at the Banner and other quarries near Danielsville.

This quarry was operated before the war by the Columbia Slate Company.

20. Three small openings, each about 50 feet square, and none showing more than 50 feet of slate above water level, are opened along the bedding strike 100 feet north of the Columbia quarry. They all show a big bed 12 feet thick, striking $N.63^{\circ}E.$ and dipping vertically. The cleavage dips more gently, showing that an anticlinal axis occurs to the south.

These quarries are said to have been last worked about 1925.

21. *Bloos Quarries.* These two small openings lie between the Locke quarry and Slatedale. The northerly one (Quarry *a*) is 75 feet square and about 35 feet deep, but filled with water at present. In it the beds strike $N.72^{\circ}E.$ and dip vertically, whereas the cleavage strikes similarly and dips $55^{\circ}S.$ It is said that this quarry opened the two big beds of the Star or Empire “run”, and the areal location of the opening with respect to the Manhattan big bed supports this

statement. It was last drained in 1925 but was not extensively worked recently.

The more southerly is a small hole, 80 feet square and probably 50 feet deep but also filled with water; the structure is much like that in Quarry 21a. The quarry is reputed to have opened the upper bed of the Keystone "run".

22. *Locke and Royal Blue Quarries.* About 800 feet north of the Slatedale Hotel are four quarries, which are so close together that they are grouped under one number. With respect to each other, they lie along the regional strike. The western is the Locke quarry and the three easterly are generally referred to as the Royal Blue openings. (See Plate 58, A).

The Locke quarry is an irregular opening, roughly in the shape of a rectangle with the west corner truncated, and measuring about 500 feet by 350 feet in maximum dimensions. The greater part of the hole is full of water, but in 1927 work was being done along the northwest edge.

Near the southwest corner the beds strike $N.65^{\circ}E.$, and dip steeply north but along the northwest edge the dip is gentler, here only 52° . Strike and dip of cleavage is $N.74^{\circ}E.$, $65^{\circ}S.$ The inference is that an anticlinal crest lies some distance to the south and a synclinal crest immediately north. This structure is shown in Figure 70, and in Structure Section G, on Plate 56.

The beds exposed are the Lower and Middle Locke big beds in the southwest part of the opening and the Upper Locke (or Manhattan) big bed on the north piece mentioned. The latter is here about 20 feet thick.

This quarry is equipped with two mills, a larger one south of the quarry for making structural slate, and a smaller just north of the opening for rough trimming. The chief products are electrical and structural slate. The quarry is one of the oldest openings at Slatedale. The present operating company is the Shenton Slate Company of Slatedale.

The three openings east of the Locke quarry are referred to as the Royal Blue quarries and are also known, beginning at the west, as the Shenton No. 2, Crescent, and Royal Blue quarries respectively. The Shenton No. 2 measures 225 by 210 feet and is 35 feet deep to water level. The Crescent is 240 by 215 feet, with a tunnel in the northwest side. The Royal Blue lies just west of the highway; it is 375 by 225 feet in surface area and is about 220 feet deep; in 1927 the chief operations centered around tunnels driven into the overhanging northwest side of the opening.

Structurally the situations in the three Royal Blue quarries are identical. The beds generally strike $N.75^{\circ}E.$; along the southeast sides of all three openings, which are essentially parallel, the dip is $75^{\circ}N.$, but it flattens northward and downward and in the eastern tunnel of the east opening it is only $8^{\circ}N.$ This flattening of the beds indicates a synclinal axis which outcrops between the Royal Blue openings and the Manhattan quarry to the north. The cleavage is roughly parallel in strike to the beds, but dips $62^{\circ}S.$ Grain trends $N.25^{\circ}W.$

The beds opened include the two lower big beds of the Locke "run", but the openings are not carried far enough to the north to intersect



A. View southwest from Kern quarries at Slatedale: Royal Blue quarry in foreground; large Locke quarry and mill in far distance. Note the waste heaps.



B. Curvature of cleavage at anticlinal crest, in bottom of Blue Mountain quarry, east corner; the beds dip gently north (right).

the uppermost Locke big bed on the north edge of the Locke quarry. The Lower Locke big bed appears on the south edge of the opening.

The synclinal axis here defined pitches east, as bedding and cleavage strikes intersect westward. Another interesting feature is the series of branching and gently dipping joints, which intersect the bedding planes so as to form acute dihedral angles which open upward to the south and downward to the northwest. These have introduced serious difficulties in tunnelling. Near the northwest edge a "loose ribbon", along which some movement has taken place, has also given trouble, particularly because of the associated joints.

The mill is south of the opening. Products include structural and electrical material and some ribboned slate.

These three quarries were opened about 1900 under different management. The eastern pit is now the only one in operation.

23. *Manhattan and Schuylkill Quarries.* These two openings are about 1200 feet north of the Slatedale Hotel, and immediately west of the road leading north from Slatedale. The westerly one is the Manhattan quarry. It measures 200 by 330 feet in area, with a depth of 180 feet, the upper 8 feet of which are glacial overburden. The opening exposes a northward overturned anticline with two big beds, of which the upper just comes to the surface at the crest of the anticline (see Figure 49); the lower, which here does not reach the surface at all, is the northern (Upper Locke, Manhattan) big bed mentioned in the description of the Locke quarry. For measurements, see Plate 39. The plane of the anticline mentioned strikes $N.80^{\circ}E.$ and dips about $45^{\circ}S.$; there is probably an eastward pitch to the fold, but the evidence is not positive.

The general cleavage strikes parallel to the axial plane of the fold. Grain trends $N.28^{\circ}W.$, dips $75^{\circ}E.$ Joints are common in the quarry bottom and strike parallel with the beds, dipping between 30° and $40^{\circ}N.$

This quarry has been operated by the Manhattan Slate Company of Slatington since 1916. The equipment includes two mills, one of which does the heavier trimming, while the other (see Figure 33) is used in the finishing of blackboards and electrical slate. The company makes all types of slate products except slate pencils.

The Schuylkill quarry is of about the same size as the Manhattan and shows identical structure. It is now flooded, having been abandoned about 1905. The west property line separates it and the Manhattan quarry.

24. *Kern Quarries.* Three quarries lie on the eastward continuation of the strike passing through the Royal Blue quarries, and 200 feet east of the latter. The three openings are about equal in area—approximately 100 by 150 feet or less—but vary in depth; thus the east quarry is said to be 230 feet deep, whereas the west opening when visited in 1927 had attained a depth of only 90 feet. The two easterly holes are abandoned and filled with water, the west one alone being operated.

In the latter opening there are 10 feet of glacial overburden, beneath which the slate beds strike $N.73^{\circ}E.$, and dip $71^{\circ}N.$ at the northwest edge, $81^{\circ}S.$ at the southeast edge. At the north edge is the Middle

Loeke big bed and the Lower Loeke big bed is just south of the south-east edge. For thickness measurements of the beds south of the Middle Loeke big bed, see Plate 39. The cleavage strikes N.75°E., dips 60°S.

An interesting fact in connection with this opening is the method of drainage. Water runs east into the next hole, which is deeper, along cleavage and joints, and the quarry company pumps from the east of these two openings to maintain the eastward drainage gradient.

These quarries are in the hands of the J. P. Kern Slate Company of Slatedale. Equipment includes two mills, one at the quarry for trimming and rough dressing, and one for finishing at Emerald (see Quarry 36). Products include structural, electrical, and roofing slate, and some school slate; for trimming the latter, circular saws, 7½ inches in diameter with 12 teeth, are used, instead of the square saws more commonly seen.

The two quarries to the east show a structure like that described above; the eastern one opened the Lower Loeke big bed in addition.

25. These two small, unnamed openings, some 300 feet east of the Kern quarries, are each about 70 feet square. The one on the west is approximately 220 feet deep; the depth of the east opening is not known and cannot be estimated, as it is filled with water. In the west opening the beds strike N.71°E., dip 83°S. This hole opened the Lower (First) Locke or Klondike big bed, which appears in the middle of the southwest side. It is said that a tunnel was run south from one of these openings and encountered the Franklin big beds.

Both of these quarries are now abandoned, the west one having been operated last in 1925, the other at a much earlier date.

26. *Standard Quarry.* These two abandoned openings lie about half a mile west of Rextown and a quarter of a mile north of the Slatedale Hotel. The eastern is rectangular and measures 95 by 80 feet; bed rock is not exposed. The west opening is 120 feet wide and 380 feet long on the strike and is reported to have reached a depth of 100 feet. The beds exposed strike N.75°E. and dip 75°N. along the south-east edge, steepening northward to vertical. They are said to have included the upper big bed of the Manhattan quarry (which see) and a part of the overlying Columbia run. The Upper Locke (Manhattan) big bed was left standing on the south side of the opening. Both openings must be on the north limb of an antiform (probably that seen in the Manhattan and Schuylkill quarries), for the cleavage dips south about 40°. The slate seen on the dump is of fair quality.

These quarries were opened about the year 1860 and shut down in 1908, the last operations being under the Standard Slate Company.

27. *Rice Quarry.* This long abandoned opening at the Slatedale Knitting Mills measures about 60 by 80 feet and is filled with water. It is said to have been in the Washington "run" which here dipped 45°N., but as no slate is exposed the statement could not be confirmed.

28. *Myers Quarry.* This opening, 2000 feet east of the Slatedale Hotel, is 100 feet square, and filled with water, so that bed rock is seen only on the southeast side, where the ground rises slightly. Here the beds strike N.75°E., dip 42°N., whereas the cleavage dips vertically. The structure is thus the south limb of the Empire syncline. Strati-

graphically the quarry lies between the Franklin and Washington "runs" and the big bed, 10 feet thick, seen in the middle of the southeast side is probably the Little Franklin bed. Operations ceased here in 1917.

29. *Blue Mountain Quarries.* These are two openings just north of the highway and about 3400 feet by road from the Slatedale Hotel. The west (Quarry *a*) is a small hole about 90 feet square, showing 45 feet of slate above water level. Tunnels are said to have been driven into its northeast and northwest walls, the latter tunnel serving for drainage. One big bed (the upper one exposed in Quarry *b*, described below) is seen at the southeast edge. The beds strike $N.75^{\circ}E.$ and dip $43^{\circ}N.$; cleavage strikes similarly but dips $70^{\circ}S.$; the structure is thus the north limb of an anticline. The quarry is not now being worked. It is used for the disposal of waste from the opening to the east.

Quarry 29*b* is a large opening, roughly rectangular, measuring about 400 by 200 feet and 125 feet deep. It exposes the anticline mentioned in describing Quarry *a* and the complementary Prudential syncline to the south. In the west corner at a depth of 50 feet the beds strike $N.70^{\circ}E.$ and dip $4^{\circ}N.$; near the middle of the opening the dip on the working level is $30^{\circ}S.$; and at a depth of 60 feet along the southeast wall the dip is vertical. Thus the crest of the anticline mentioned in describing Quarry *a*, as well as the trough of the complementary syncline to the south are defined. The syncline has an axial plane striking $N.83^{\circ}E.$ and dips $55^{\circ}S.$ and the fold pitches $5^{\circ}E.$ Measurements of the strata are given in Plate 40. There are three big beds, of which the upper (also seen in Quarry *b*) is 13 feet thick and the middle and lower are respectively 22 and $6\frac{1}{4}$ feet in actual thickness. Besides being worked in the quarry bottom, the lowest big bed is mined along a tunnel in the northeast wall, but it rises so as to pass into the southeast quarry wall as it is followed south. For the general structure, see Figure 71.

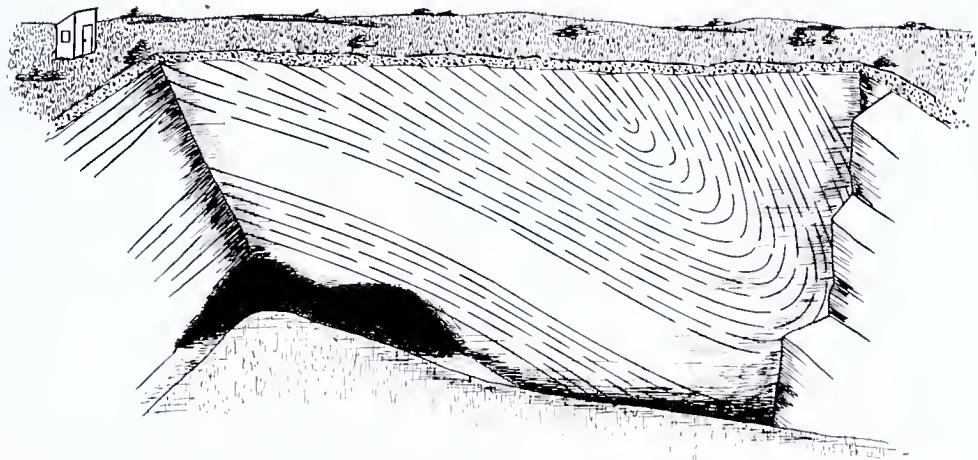


Fig. 71. Northeast wall of Blue Mountain quarry near Slatedale, showing Prudential syncline and anticline north of it.

Near the trough of the syncline there is pronounced false cleavage on planes striking $N.75^{\circ}E.$ and dipping $43^{\circ}N.$, accompanied by the usual curvature of the cleavage planes. Here also there is a "loose

ribbon" (movement on the bedding plane), along which are numerous small, closely spaced, calcite filled joints striking $N.5-15^{\circ}E.$, and standing more or less vertically.

This quarry is equipped with a small mill, consisting of a two-story building, the upper floor being used for lumber stock and as a repair shop. The present production includes structural slate, blackboards, and electrical slate, and some roofing slate.

The Blue Mountain quarries were opened in 1860 and since then have passed through many hands. At present they are operated by the Blue Mountain Slate Company, which acquired the property in 1898.

30. *Bucktown (Dilliard) Quarry.* This old opening is about 400 feet east of the east Blue Mountain quarry. It is roughly rectangular and measures 135 by 270 feet. Bed rock shows in the walls, especially along the northwest side, but water fills the opening. The glacial overburden locally attains a thickness of 28 feet.

This quarry is along the strike of the structures seen in the larger Blue Mountain opening, and is thus in the Blue Mountain "run". One big bed, probably the uppermost of the Blue Mountain quarry, is seen at water level. The anticlinal crest emerges just north of the north corner of the opening, and here the beds strike $N.72^{\circ}E.$ and dip about $10^{\circ}N.$ Cleavage strikes $N.70^{\circ}E.$, and dips $40^{\circ}S.$

The quarry was opened about 1900, and operated by the Empire Slate Company until 1917.

31. Five openings, close together and a little north of the Blue Mountain quarries, are situated east of the highway, midway between Slatedale and Emerald. Four of these (numbered *a*, *b*, *c*, and *d*, from the east westward) are in a line; the fifth (*e*) is about 150 feet northwest of Quarry *c*.

The east opening is 160 by 75 feet in area and 90 feet deep. It shows beds which strike $N.70^{\circ}E.$ and dip $81^{\circ}N.$, but steepen downward. There are two big beds (Trout Creek big beds) of which the thicknesses are 19 and 24 feet, respectively, for the south and north beds, with 24 feet of thinner layers between. Cleavage strikes $N.70^{\circ}E.$ and dips $40^{\circ}S.$ The grain trends $N.27^{\circ}W.$

Quarry *b* is structurally like Quarry *a* and has an arm-like projection on its east side. It exhibits only the southerly of the two big beds mentioned above. Quarry *c* also resembles Quarry *a*. Quarry *d* is a shallow cut in the hillside east of the street railway tracks and highway; it exposes one big bed which shows the same structural relations as seen in the quarries to the east.

Quarry *e* is an old hole, long deserted, and said to have been opened in the Penn Lynn "run", which underlies the Washington beds.

All these quarries are now abandoned and none of their equipment remains.

32. *Roberts and Peters Quarries.* East of Quarry 31 *a* are six openings of various sizes and depths. Beginning at the west, they may be lettered *a* to *f*. Quarry *a* is 165 by 60 feet in area and 60 feet deep to water level. It shows beds that strike $N.72^{\circ}E.$ and dip 90° at the north, $65^{\circ}N.$ at the south edge. Cleavage strikes $N.44^{\circ}E.$ and dips $44^{\circ}S.$

The three quarries east of Quarry *a* are generally called the Roberts quarries. They are small openings averaging 100 feet on the side and 80 feet in depth. Like Quarry *a* and the other quarries numbered 32, they are in the Trout Creek "run" and one or both of the Trout Creek big beds show in each opening, striking $N.72^{\circ}E.$ and dipping steeply north or vertical at the surface. The cleavage strikes $N.77^{\circ}E.$ and dips $52^{\circ}S.$ Grain trends $N.22^{\circ}W.$

Quarries 32 *e* and *f* (Peters quarries) are near to and east along the strike continuation from Quarry 32 *d*. They are 100 feet square and about 80 feet deep, and show the Trout Creek big beds, which are here 17 (Lower Trout Creek) and 19 (Upper Trout Creek) feet thick, with 22 feet of lesser beds between. The strata dip $82^{\circ}N.$ at the surface, but steepen and even dip southward at the bottom. Cleavage and grain are as in the other quarries of like number.

The Roberts and Peters quarries were operated with success until the early years of the World War (about 1917), when labor difficulties forced cessation of operations.

33. *Keim Quarries.* These are long abandoned. They are situated about 1600 feet due west of Rextown. The east opening is 60 by 105 feet in area and filled with water. One big bed (thought to be the Manhattan, Upper Loeke), 11 feet in actual thickness, shows in the northeast side. Structurally the quarry is south of a synclinal axis (probably the Eureka syncline), as the beds dip $60^{\circ}N.$ in the east side but flatten to a dip of $20^{\circ}N.$ at the north corner. The bedding strike is $N.50^{\circ}E.$ Cleavage strikes $N.70^{\circ}E.$ and dips $57^{\circ}S.$ This eastward convergence in strike of beds and cleavage suggests a west pitch of the structure. Grain trends $N.30^{\circ}W.$

The west opening is larger, being 215 by 120 feet in area. Some slate shows on the southwest wall. Structurally the relations are as in the eastern opening, except that a gentle south dip is seen at the northwest edge.

These two quarries were opened about 1890 and last operated in 1915.

34. *Empire Quarries.* These are half a mile west of Emerald and 600 feet north of the highway. The larger (west) quarry is a landmark for most of the surrounding country.

The east opening (Quarry *a*) is a small hole, 125 by 70 feet in area and 45 feet deep to water level. A synclinal fold is visible in its east wall; this structure will be more fully described in what follows. The quarry has had only a small production and is not now worked.

The west opening, to which the name Empire quarry is generally restricted, is also known as the Oplinger quarry. It is a very irregularly shaped opening, roughly 400 by 200 feet in size. The maximum depth is 90 feet, but the working hole more recently developed along the southeast side of the opening is 60 feet below the surface. Here the beds strike $N.85^{\circ}W.$ and dip $40^{\circ}N.$, whereas the cleavage strikes $N.82^{\circ}E.$ and dips $55^{\circ}S.$ In the north corner of the quarry, however, the beds strike due north and dip $15^{\circ}E.$, thus outlining a synclinal axis, which here trends about $N.80^{\circ}E.$, and pitches east 18° .

The quarry shows, in addition to the syncline mentioned, an unusual structure suggested in Figure 72. Several lower beds, when

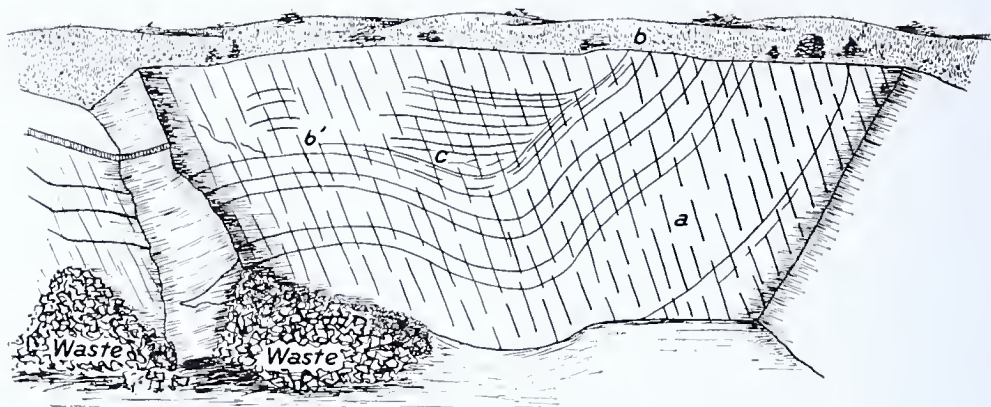


Fig. 72. Empire quarry,—northeast wall from quarry floor. The cleavage dips steeply south. The beds show the Empire syncline, but the lower strata are more closely folded than the upper, and a bedding slip fault is developed along the bedding plane *b-b'*. The Lower Star big bed is at *a*. A heavily shattered bed is almost completely cut out at *c*.

viewed along the axis of the syncline, show the fold clearly, but higher beds, poorly defined, do not take part in the curvature of the trough but are truncated instead by the lower beds themselves. This and the heavy shattering and jointing (not shown in the sketch) suggest a shearing movement roughly along the bedding of the lower strata, similar to the bedding slip faulting described on page 166, but along a plane that is nearly horizontal, instead of nearly vertical. Beds well above the zone of movement are intact and continuous until they meet the upturned edges, but those in immediate contact with it at the base of the synclinal trough are heavily shattered and dismembered, being preserved here and cut out there, in irregular masses. The extent of the stratigraphic gap produced by the faulting is measurable in the following comparison, which gives the sequence at the bedding slip fault near the north corner of the Empire quarry and that in the Eureka quarry, where the same general sequence is recognized and there is no faulting.

The shattered zone evidently represents the cutting out of a thickness of beds between 35 and 70 inches; the quantitative uncertainty is introduced by the evident general thinning of the sequence in the Empire quarry.

The quarry shows in addition some irregularities in bedding (see Figure 73), as well as some almost horizontal joint planes. On the

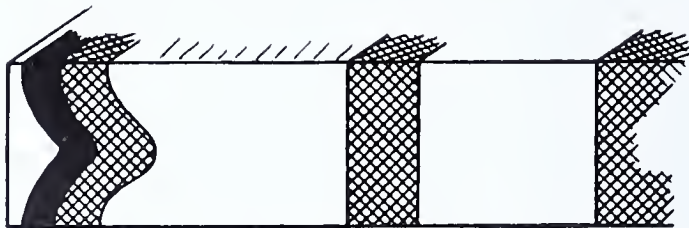


Fig. 73. Irregularities in block of banded slate at Empire quarry. The "ribbon" to the left shows folding, whereas that to the right does not. X $\frac{1}{4}$.

Table for comparison of sequences.

| Eureka quarry | | Empire quarry | |
|--|-----------|--|-----------|
| Description | Thickness | Description | Thickness |
| Very big bed | 13½ ft. | Very big bed | 12½ ft. |
| Light bed | 23 in. | Shattered zone | 18 in. |
| Dark bed | 1 in. | | |
| Light bed | 9 in. | | |
| Dark bed | 2 in. | | |
| Light bed | 6 in. | | |
| Dark bed | ½ in. | | |
| Light bed | 17 in. | | |
| Dark bed | 1½ in. | | |
| Light bed | 17 in. | | |
| Dark bed | ½ in. | | |
| Light bed | 11 in. | Light bed | 41 in. |
| Dark bed | ½ in. | | |
| Light bed | 18 in. | | |
| Dark bed | 1½ in. | | |
| Light bed | 32 in. | | |
| Dark bed | ½ in. | Dark bed | ½ in. |
| Hard bed with prominent sandy base | 45 in. | Light bed | 29 in. |
| | | Dark bed | 1 in. |
| | | Light bed | 1 in. |
| | | Dark bed | 3 in. |
| | | Hard bed with prominent sandy base | 77 in. |

present working level the joints strike N.72°E., some dipping 18°S., whereas the others vary in dip up to 34°N. From what is known of bedding slip planes in other quarries, it may be inferred that the prominent joints are related to the slippage noted.

Production here is in the hands of the American School Slate Company and is aimed chiefly at supplying the factory of the company which is located near Emerald. Quarry operations were begun in 1860.

The machinery includes the usual mill for structural slate and equipment for a small production of school slates.

35. *Custer Quarry.* This is a small vertical opening with a long tunnel and may be regarded essentially as a shaft. It is located at the turn of the highway, about 750 feet southeast of the Empire quarry. It was 125 by 90 feet in area, and was 140 feet deep in 1928. Forty feet below the present bottom a 200-foot tunnel leads northwest, down the dip, on the Lower Franklin big bed, but work on this level has been discontinued and the lowest 40 feet of shaft have been filled with waste. When visited in 1927, operations were carried on at the new tunnel level mentioned in the Upper Franklin big bed.

A thin overburden of glacial material covers the bed rock. Beneath this the strata show a small buckle, scarcely to be regarded as an anticline, the axis of which passes into the southeast wall at a depth of 65 feet.

At tunnel level (140 feet) the beds strike N.50°E. and dip 38°N., but flatten northward (down the dip) to 15° and southward (20 feet up the dip) as well, being virtually horizontal a short distance up in the "shaft". The Upper Franklin big bed here is 17 feet thick; data supplied by the quarry foreman indicate that the Lower Franklin is 25½ feet thick and that the intervening beds are 18 feet in actual thickness.

Cleavage strikes approximately N.72°E. and dips 58°S.; grain trends N.33°W., and dips steeply eastward. An interesting structural feature is the false cleavage or "curl", which is prominent in at least two

places in the Upper Franklin big bed, the planes of the little cleavage folds striking N.65°E. and dipping 35°N. It is noteworthy that at this occurrence of false cleavage a westward convergence in the strikes of cleavage and bedding suggests a pitch—here to the west—of the structure, a condition generally accompanying false cleavage when it is present in the larger beds (see pages 36 and 279).

This opening is equipped with a small mill; the chief product is roofing slate, which sells at a premium, as coming from the Franklin bed. Some school slate is also made. An interesting feature is the generation of water power by the fall of water pumped from the hole. The opening has long been productive and was taken over by the present operators in 1922.

36. Two old openings lie on either side of the railroad tracks and Trout Creek about 750 feet southwest of Little Run Junction. The southeast one is about 70 feet square and filled with water. A well-equipped mill still stands south of the hole, and is operated as an accessory to that at the Kern quarries, Slatedale. There is no exposure of slate here, but nearby outcrops in the railroad and road cuts to the east, as well as general areal relationships, suggest that the beds quarried are in the Blue Mountain "run", north of the crest of an anticline. The beds probably dip vertically.

The northwesterly opening is 80 by 110 feet in area and shows a little slate above water level. Here the beds strike N.72°E., and dip 68°S., whereas the cleavage dips 42°S. Structurally, therefore, this quarry is situated similarly to that just described. No big beds are seen.

Nothing is known of the history of these two openings.

37. *Ellis Owens Quarries.* These three openings are approximately along the same strike-line as the Custer quarry; they are situated southeast of the highway and east of the quarry mentioned. They may be designated *a*, *b*, and *c*, beginning at the west and progressing eastward.

The west opening is about 130 by 200 feet in size and virtually rectangular; its depth to bottom is estimated at 60 feet, but water fills most of the hole. There is no appreciable overburden. In the southwest wall a sharp, northward-tilted antiline is clearly shown, with one exceptionally big bed at the top. In the southeast corner the beds strike N.65°E., and dip 32°S., on the south limb of the antiline, whereas the cleavage strikes N.68°E., dips 70°S. The axial plane of this fold dips 60°S.; it pitches west, for at the north edge of the opening the beds strike N.30°E., with steep north dips.

Though measurements were made with care, the stratigraphic position of the beds here exposed could not be established. The exceptionally big bed mentioned is about 21 feet in actual thickness, and measurements of the sequence above it suggest that it is the Lower Franklin big bed, but the correlation is not certain.

About 50 feet east of the opening there is an irregular quarry showing 30 feet of slate above water level. It exposes the same antilinal crest as was seen in the quarry to the west. It has been long abandoned, and was last worked by the Carbon Slate Company.

Some 200 feet still farther east, and across Trout Creek is a small opening, 90 by 70 feet in size, filled with water, and probably about 50 feet deep. No slate shows in place. An old mill building stands a short distance from the hole. This pit was last worked by the William Williams Company, some time before the World War.

38. *Owen Williams Quarries.* These two abandoned quarries lie about 400 feet north of the Ellis Owens quarries and north of the highway and traction line. The west opening is small and rectangular 50 feet square and not over 12 feet deep. It shows beds striking N. 75° E. and dipping vertically; one of these is about 15 feet thick, and, though not accessible to measurement, is thought from its structural relations and areal position to be the Lower Star big bed.

The east opening is much larger, being 90 feet wide and 450 feet long. It is filled with water, but 15 feet of slate, covered by 10 feet of glacial overburden, are visible, and a large dump toward the south points to extensive operations. In the south end two big beds show clearly, the upper being 18, the lower (also noted in the quarry just described) 15 feet thick; the two are separated by 20 feet of "ribbed" slate. These are correlated with the Upper and Lower Star big beds. The structure is evidently the south limb of the Empire syncline, for the bedding strikes N. 78° E. and dips vertically, whereas the cleavage dips 50° S.

It is not known how recently operations ceased here. A mill northeast of the openings and across a secondary road belonged to the company. The last operator was Owen T. Williams.

39. *Parry Quarry.* This is a large opening 200 feet east along the strike from the Owen Williams quarries. It is irregular in shape, with maximum dimensions of about 400 by 300 feet. On the northerly sides about 50 feet of slate are exposed. These exposures display much small scale wrinkling, but the general structure is anticlinal, the beds being essentially horizontal along the southeast side, but dipping about 74° N., with a strike of N. 72° E. on the northwest edge. The beds are probably those of the lower part of the Star "run".

Slate on the dump shows much cross-bedding in the sandy layers, (Figure 74) and "curl" (false cleavage) is also present in such beds.



Fig. 74. Parry quarry; detail of cross-bedding in a sandy layer. The cross-bedding is toward the west (left), showing that these currents came from the east. X 1/10.

This quarry was operated by the Slatington Slate Company from 1875 until 1925; it is now idle.

40. *Emerald Quarry.* This opening is on the southeast edge of the little town of Emerald. It is about 200 by 90 feet in area, of irregular outline. On the southeast edge 30 feet of slate show above the water with which the quarry is filled, but the surface declines north to water level.

The beds strike N.68°E. and dip steeply south at the south edge of the opening, more gently north at the north edge, showing that there is an antieclinal axis to the south. The cleavage strikes N.80°E. and dips 33°N. Grain trends N.27°W. and dips 85°E.

Two big beds show near the southwest edge, a lower one 9 feet thick, and an upper 6 feet thick, separated by 9 feet of thinner beds. These are probably in the Kuntz "run", which lies between the Blue Mountain and Williamstown "runs" and is also exposed in part of Quarry No. 15.

Nothing is known of the history of this quarry.

41. A small pit, 100 by 40 feet in size, is located about 400 feet southwest of the west Hazel Dell quarry and 100 feet north of Trout Creek. It is thought to be about the horizon of the Blue Mountain "run"; one big bed, the stratigraphic position of which could not be definitely ascertained, shows in the west corner. The bedding here strikes N.65°E., and dips 58°S.; cleavage strikes N.83°E. and dips 43°S. The structure is thus the north, overturned limb of an anticline. Nothing is known of the history of this quarry; it has evidently long been idle.

42. *Old Franklin Quarries.* East of the Parry quarry and a little south of its eastward strike continuation is a line of almost continuous openings extending for 2000 feet along the Franklin "run". The middle of this stretch is occupied by one exceptionally long excavation described below as the Big Franklin. West of it are three separate openings, of which the western is generally called the Old Franklin and the east two the Steckel quarries. In this report all three of these are referred to as the Old Franklin.

The two westerly of the Old Franklin openings are each about 120 feet square. Each shows 50 feet of slate in the northwest wall. Bedding and cleavage strike N.70°E., the beds dip 10°N. and the cleavage 56°S. Minor crumpling, resembling that described in the Parry quarry, is also seen.

The east opening is larger, being about 225 feet square. It, too, is flooded, but 25 feet of slate are seen above the water, covered by 18 feet of poorly stratified overburden. The beds are horizontal along the north edge, and dip 43°N. along the southeast side. Their strike is N.50°E., whereas the cleavage strikes N.80°E. and dips 52°S. The westward convergence of the strikes of bedding and cleavage, coupled with the north dip of beds suggest a westward pitching anticline, the opening being in the north limb. No conspicuous big beds are seen, but the strata worked were probably in the Franklin "run".

The equipment for this group of openings has been removed. The quarries are in part very old, one of them dating to 1846. The west opening is said to have been operated by the Slatington Slate Company. The two east openings were first operated by the Steckel Slate Company. All have been abandoned for some time.

43. *Big Franklin Quarry.* This is the largest excavation in the Slatington region, being about 1000 feet long and 130 feet wide. The depth is said to reach 250 feet, maximum. Strictly speaking it consists of five separate openings with narrow dividing walls between, but the latter are not visible now on account of the high water level. These

separate holes, in order eastward were called the Steckel quarry, the two Carbon (Woods) quarries, and the two Griffith Brothers quarries. Since the geology is essentially alike and the separating walls are not visible, these will all be lumped together under one name and description.

Generally 20 to 40 feet of slate show above water level on the southeast and northwest sides of this long cut; the bed rock is covered with an overburden of 28 feet of glacial material, and the sides have been further heightened by waste heaps.

The quarry is opened just north of an anticlinal axis, and the beds dip steeply north as a consequence. The general strike of the bedding is $N.65^{\circ}E.$, and the dips vary between 68° and $73^{\circ}N.$ At some depth the dip is reversed, so as to be southward and this south dip is said to be maintained to the greatest depths reached. The cleavage strikes $N.72^{\circ}E.$ and dips $52^{\circ}S.$ Grain trends $N.28^{\circ}W.$ and forms vertical planes. There are variations in the direction and degree of pitch of the structure as indicated by the traces of beds on cleavage planes; the pitch is nowhere great, however.

This series of openings lies along the big beds of the Franklin "run". The bottom of the Lower Franklin big bed forms the southeast side of the present opening and the top of the Upper Franklin big bed shows in the middle of the southwest wall.

No equipment remains nearby. Most of the quarrying was carried on between 1880 and 1917, when the last of this "Golden Line", the Carbon quarry, was shut down, the Griffith having been closed in 1911, and the Steckel quarry yet earlier. This group was probably the most profitable of all of the Slatington quarries.

44. *Provident and Hazel Dell Quarries.* These seven quarries form a line along the strike with respect to each other, and may thus be discussed together. They are situated 1000 feet north of the railroad, between Emerald and Slatington. The western three are the Hazel Dell, the next three easterly are the Provident, and a small hole still farther east is an accessory opening to the East Carbon quarry. For convenience they may be numbered from *a* to *g*, beginning with the west opening and going east.

Quarry *a* measures 100 by 135 feet in plan and shows 25 feet of slate above water level. The beds strike $N.57^{\circ}E.$ and dip $85^{\circ}N.$, whereas the cleavage strikes $N.73^{\circ}E.$ and dips about $45^{\circ}S.$ The Upper Washington big bed shows at the surface near the middle of the northeast side, but the Lower Washington big bed is not exposed. The quarry is opened on the north limb of an anticline, the westward pitch of which is indicated by the westward convergence of the bedding and cleavage strikes.

Quarry *b* shows much the same dimensions and structure as Quarry *a*. Quarry *c* is also similar, but the beds dip much more gently north and show a slight roll. Two big beds, the Upper and Lower Washington, are clearly seen in the east wall here; they are further described below.

Quarries *d*, *e*, and *f* are similar in size, measuring on an average about 120 feet square. The bottoms are filled with waste and water. In them the beds strike $N.67^{\circ}E.$ The dip varies greatly: in Quarry *d* the beds are horizontal in the southeast corner, but dip vertically or steeply southward at the northwest edge. A minor anticlinal fold is

thus exposed. Quarries *e* and *f*, however, are north of the strike of this fold and thus show only the steeply dipping north limb. They were both opened in two big beds—those of the Washington “run”—and the intervening “ribbons.” The Upper Washington big bed is here 19 feet thick, with $19\frac{1}{2}$ feet of “ribboned” slate between it and the Lower Washington big bed, which is about 20 feet thick.

The average strike of cleavage in these easterly openings is about N.80°E., with a dip of 45°S. Grain trends N.22°W. and dips 85°E.

Quarry *g* is a small opening 75 feet square, 70 feet deep to water level. It shows the Lower but not the Upper Washington big bed, here striking N.70°E. and dipping 73°S. A tunnel leads east from this opening.

These several holes have had a highly varied history. They were extensively worked in the “boom” days, and one—which of them is uncertain—is said to have been sunk to a depth of 430 feet. All were important producers from the Washington “run.”

45. *Peters Quarries.* These two openings lie east along the strike continuation of the Big Franklin quarry and immediately adjacent to the latter. The west opening is 220 feet by 125 feet in size and the east is 75 by 125 feet. Depth to water level in both is about 80 feet.

The two Franklin big beds were worked in these quarries; the east opening has the Upper Franklin big bed forming its northwest edge and the west opening shows the Lower Franklin big bed along its southeast side. (Plate 59, B.) The strata strike N.65°E. and dip north, varying from 60° at the south edge to vertical along the northwest quarry sides. They steepen at depth and finally turn to dip south, thus evidently being on the crest of an antiline which here pitches gently west. Cleavage strikes N.67°E. and dips about 40°S.

Jointing is conspicuous, especially in the west opening. The large beds show it best, probably because inter-bed movement served in lieu of jointing in the thinner layers. That the bedding planes were roughly parallel to the ideal planes of movement is shown by the fact that joints in many places cut the larger beds parallel to stratification planes, so that these beds come to suggest a series of thin strata. The dip of many joints also approaches horizontality; thus, in 15 observations of the dip, only one was steeper than 42°.

The history of these quarries is uncertain and much the same may be said of their property lines. The east opening was for a time at least operated by the company that quarried slate on the Fairview properties (see Quarry 46.) Presumably both have been shut down since the depression of 1917.

46. *Fairview, East Carbon, Old Columbia and nearby Quarries.* Nine openings lie east of the Peters and Provident quarries, halfway between Emerald and Slatington and about 1000 feet north of the highway. These are so closely spaced that separate numbering on the small scale map is not possible. Figure 75 is a key map to serve in the description. In this figure only the lettered openings are included under Quarry No. 46. The letters used in that figure correspond to the text designation.

Quarry *a* is only 40 by 40 feet in size and perhaps 20 feet deep, now filled with waste and water.

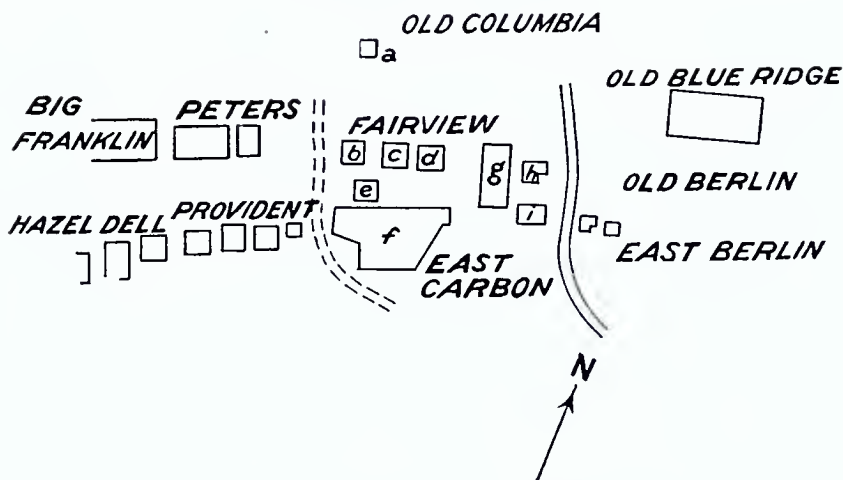


Fig. 75. Sketch map of Quarry 46 and adjacent quarries to serve as key in locating.

Quarries *b*, *c*, and *d*, (the Fairview openings) lie along the strike from each other, 600 feet northeast of the east Quarry No. 45. They measure 40 by 80, 65 by 105, and 65 by 100 feet respectively from the west eastward. In depth all are about 80 feet to water, but may well be deeper. The beds strike $N.70^{\circ}E.$, dip $85^{\circ}N.$, steepening at greater depths to vertical. The cleavage strikes $N.70^{\circ}E.$ and dips $45^{\circ}S.$ Grain trends $N.30^{\circ}W.$ and is vertical.

In the northeast and southwest walls are excellent exposures of the Franklin big beds. The Upper is here 13, the Lower 17 feet thick, and the two are separated by 13 (?) feet of "ribboned" slate.

The company that quarried here had connections between the openings by tunnel, and extended its operations southward as well so as to carry them beneath the north wall of the East Carbon quarry, which necessitated the payment of a royalty to the operators of the latter.

Quarry *c* is actually a northward projection from the East Carbon quarry. It is 80 by 150 feet in areal dimensions and 70 feet deep. Near its southeast edge the Little Franklin big bed outcrops, here 14 feet in thickness. The beds strike $N.63^{\circ}E.$ and dip $70^{\circ}N.$

Quarry *f*, the East Carbon quarry, was once a very profitable opening of highly irregular shape. Its maximum length at right angles to the strike is 310 feet and its width 525 feet; 70 feet of slate are visible in the present walls. The beds shown extend upward from the Upper Washington big bed; this bed shows in a bridge-like projection near the southwest side of the quarry. The Lower Washington big bed lies beneath the dump south of the quarry. The beds here laid bare are on the north limb of an anticline. Dip varies from $70^{\circ}S.$ at the south edge of the opening, to $58^{\circ}N.$ along the northwest side; the general strike is $N.60^{\circ}E.$ The cleavage strikes similarly, dips $42^{\circ}S.$ This was one of the most productive quarries at Slatington.

Quarry *g* is generally referred to as the Old Columbia. It is 55 by 300 feet in ground plan and 80 feet deep to water level, but probably much deeper yet. It is opened along the outcrop of the two Franklin big beds, of which the Upper is here $14\frac{1}{2}$ feet in thickness, and separated by $13\frac{1}{4}$ feet of "ribboned" slate from the Lower Franklin big

bed, which is $16\frac{3}{4}$ feet thick. In the extreme south end of the opening, the Little Franklin big bed, already mentioned in describing Quarry *e*, is seen. The beds steepen northward, so as to dip 80°N . near the northwest edge, though the dip is only 66°N . along the southeast side; this structural relation is like that in the Fairview openings already described. Cleavage strikes $\text{N.}70^{\circ}\text{E}$. and dips 47°S .; grain trends $\text{N.}37^{\circ}\text{W}$. and dips 85°E . This quarry was operated by the Steckel Slate Company, which first opened the Washington beds to the south (in the present East Carbon quarry), and then worked north, transverse to the strike, piling up new waste in its abandoned hole to the south and ultimately quarrying the Little Franklin and the Upper and Lower Franklin big beds.

Quarry *h* is an irregularly L-shaped opening with maximum dimensions of 225 by 200 feet. It is filled with water, but the depth is estimated to attain 100 feet. At the north corner the beds strike $\text{N.}67^{\circ}\text{E}$. and dip 85°S ., but steepen southward so as to dip steeply north, which suggests the approach of a synclinal axis to the north. The two Franklin big beds are exposed, the Upper showing along the northwest side of the quarry. Cleavage strikes $\text{N.}67^{\circ}\text{E}$., and dips 45°S . Grain trends $\text{N.}29^{\circ}\text{W}$., dips vertically.

Quarry *i* has its longer dimension in an east-west direction. It is 50 by 110 feet in size and shows a little slate in the southeast edge above the water with which it is filled. Here the beds dip 73°N . One bed 12 feet thick is seen near the south corner; this is probably the Lower Washington big bed.

This and Quarry *h* were operated by A. P. Berlin, but have been long shut down. They are frequently referred to as the Old Berlin quarries.

47. *Williamstown Quarries*. This is a group of three openings half a mile east of Emerald and 200 feet north of the highway. They may be lettered from the west eastward, *a*, *b*, and *c*. Quarry *a* is an L-shaped hole having a maximum length of 215 feet and a width of 65 feet. Only a small amount of slate is actually exposed above water level. The beds strike $\text{N.}67^{\circ}\text{E}$. and dip 61°S ., whereas the cleavage strikes $\text{N.}77^{\circ}\text{E}$. and dips 43°S ., which suggests the north limb of an anticline tipped to the north.

Quarry *b* is 150 feet west of Quarry *c*. It is a small opening of irregular shape showing no slate in place above water. It is said to have furnished access to a tunnel.

Quarry *c* is the largest, being 140 by 265 feet in size, and is roughly rectangular. It now serves as an ice pond. No slate is seen in place above the water.

It is generally agreed among quarrymen that these openings were in the Williamstown "run" and Quarries *a* and *b* are both reported to have produced slate from the two Williamstown big beds.

Quarry *a* was opened by Henry Williams and Quarry *b* by Nicholas Owens in 1910. Quarry *c* is a part of the Hughes group of quarries (which see under Quarry 48). None of these has been active since 1910.

48. *Hughes Quarries*. These two openings, on opposite sides of the Emerald-Slatington highway and a thousand feet southwest of the National School Slate Factory, are very old, having been described

by Sanders¹ as active in 1880. the west pit is the smaller; it lies directly west of the highway, measures 175 by 115 feet, and is filled with waste, so that very little slate is visible. Structurally this is like the eastern opening.

The east quarry is 500 by 180 feet in size, the maximum dimension being along the strike. It shows 80 feet of slate along the southeast side. The structure is complex, the beds along the southeast side striking N.68°E. and dipping 15°S., whereas the cleavage has a gentler dip to the south; along the northwest edge, however, the dip is 28°N. This structure is interpreted as a flat syncline, the axis of which emerges along the north side of the opening (see Figure 76). The Lower Williamstown big bed still shows along the south quarry edge. The Upper big bed, however, is nowhere visible; it should outcrop in the bottom of the opening.

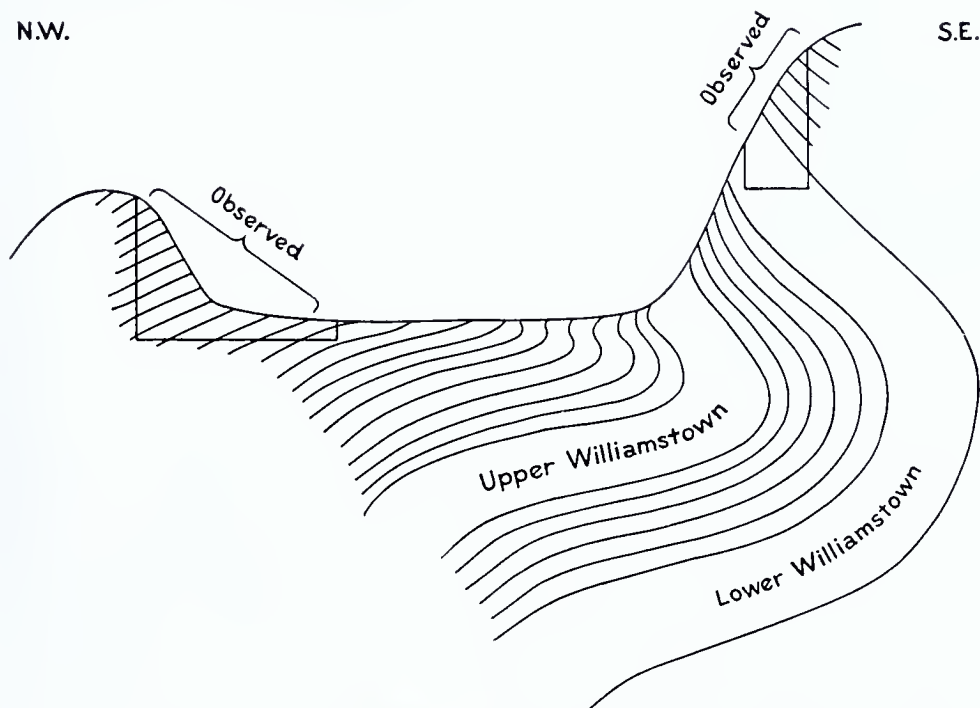


Fig. 76. Section across eastern Hughes quarry, between Emerald and Slatington, to show inferred structure. The parts accessible to observation are indicated.

The slate on the dump is sandy and somewhat faded and some pieces show noteworthy development of fracture cleavage.

These quarries were opened by Henry Williams but later operated by William Hughes. They were abandoned about 1900.

49. Two small openings, long abandoned, are situated about 700 feet northwest of the Williamstown quarries, overlooking Tront Creek. The easterly or main opening is a cut in the hillside, 70 by 60 feet in size. It exposes about 50 feet of slate, including one bed 18 feet thick (see Plate 42.) The correlation of this sequence is uncertain, but

¹ Op. cit., p. 117.

the big bed may well be the Upper Blue Mountain big bed,—an interpretation generally accepted by quarrymen and favored by structural and areal relations.

On the northeast side the beds strike $N.70^{\circ}E.$ and dip $60^{\circ}N.$; cleavage strikes $N.70^{\circ}E.$, dips $45^{\circ}S.$ The structure is inferred to be the north limb of an anticline; this interpretation is favored by the steepening of the beds at depth. Grain trends $N.42^{\circ}W.$ and is vertical.

The smaller opening, 250 feet west, is 30 by 30 feet in area; it shows essentially the same structure, but is topographically and structurally lower, so that the beds dip south.

Nothing is known of the history of these two quarries.

50. *Roth Quarries.* About 1400 feet north of Rextown, on opposite sides of the northward road, are two old, long abandoned quarries. The west opening is about 100 feet west of the road; the east quarry is 500 feet east of the road and of the Rextown school. Neither shows slate in place, and no data are available as to structure or stratigraphy. Both are little more than prospects, opened by Milton Roth about 1900.

51. *Blue Valley Quarry.* This large, irregular opening is the west one of several extensive quarries situated about half a mile northeast of Rextown. Its maximum areal dimensions are about 685 by 400 feet, and some 40 feet of slate are visible above water level, covered by a thickness, locally amounting to 30 feet, of glacial till.

This opening shows two close folds, the Eureka syncline and the complementary anticline to the south. Both are tipped northward, so that the axial planes, which strike about $N.75^{\circ}E.$, dip $60-65^{\circ}S.$ The anticlinal axis emerges at the surface about 255 feet north of the southeast edge of the quarry and the synclinal axis about 250 feet farther north. At the northerly edge of the opening there is evidence that the beds are flattening again near a second anticlinal crest.

Three big beds are seen here. One of these comes to the surface at the extreme southeast corner of the opening on the south limb of the anticline, intersects the surface once more on its north limb at about the middle of the opening, and reappears at the north edge on the north limb of the syncline already described. This is the Upper Star (Upper Empire, Upper Eureka) big bed. The next big bed below, which just fails to reach the surface at the northwest edge of the opening can be correlated by measurement with the lower big bed in the Empire quarry. The highest big bed exposed is that preserved in the syncline,—the Klondike or Lower Locke big bed also seen in the Locke, Royal Blue, and Kern quarries at Slatedale. For these structural relations, the reader is referred to Figure 8.

Shattered drill cores (see Plate 13, A) suggest the presence of a zone of movement at depth in the northwest end of the opening. This quarry was first opened about 1875. Subsequently it passed through many different hands until it came into the possession of the Blue Valley Slate Company, the present owners. It was shut down at the beginning of the World War. Recently exploratory drilling has been carried on at the north edge of the opening.

The mill and finishing equipment at the north end of the quarry were being leased to the Keystone Slate Company by the owners of the Blue Valley quarry, when visited in 1927.

52. This small opening is situated just across the railroad spur, about 400 feet east of the south corner of the Blue Valley quarry. No slate is visible above water level. The opening is 75 feet square and long abandoned.

53. *Eureka and Mountain Quarries.* Three quarries lie close together about 1200 feet east of the Blue Valley quarry and on the strike continuation of its structure and beds. Beginning at the west, they may be designated *a*, *b*, and *c*.

Quarry *a* is the Old Eureka quarry. It is rhomboid in shape, and about 200 by 350 feet in size, with the longest dimension northwest. Depth to water level is about 135 feet. Beneath 8 feet of glacial overburden bed rock is exposed. This shows the same two folds noted in the Blue Valley quarry. The axial planes strike somewhat more northerly here, approximately $N.65^{\circ}E.$ Detailed observation in the syncline shows that the cleavage planes flare, fan-like, downward (see Figure 77). In this fold joints striking $N.70-80^{\circ}E.$ are seen to dip $5-15^{\circ}S.$ on the south limb and $10-20^{\circ}N.$ on the north limb; their attitudes thus appear to be definitely related to the folding. At the north edge there is again the flattening observed in the Blue Valley quarry, for the beds strike $N.72^{\circ}E.$ and dip only $35^{\circ}S.$; evidently the anticlinal axis mentioned in describing the Blue Valley opening is not far north of the northern edge of the Old Eureka quarry (Fig. 48).

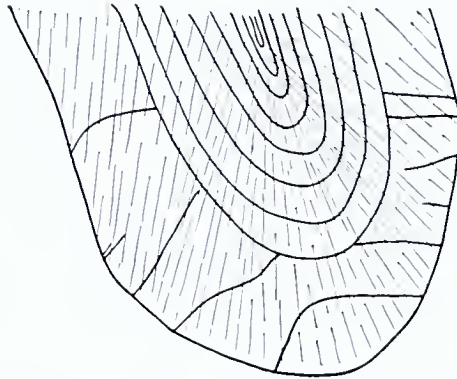


Fig. 77. Detailed sketch of syncline with Klondike big bed and higher strata, as seen in east wall of Eureka quarry. Note thickening of fold at crest and north limb, as compared with south limb; note especially the radiating arrangement of the cleavage and the attitude of joints.

The strata exposed include the same three big beds as at the Blue Valley quarry; they are shown in Figure 48. The Lower Star is the highest bed of the anticline to reach the surface; the Klondike is the big bed in the synclinal axis; and the Upper Star outcrops midway between the two.

This quarry is not now operated.

Quarry *b* is smaller, being approximately 125 feet wide and 210 feet long. It is the New Eureka quarry. As this opening lies only about 100 feet east of the Old Eureka, and directly along the strike continuation, it shows essentially the same structure, the Lower Star big bed coming to the surface at the anticline. Quarrying has not been

carried far enough north to expose the Eureka syncline, however, and so the Klondike big bed is not worked (see Figure 8), the clear stock being furnished by the Lower and Upper Star big beds.

Near the axis of the anticline prominent openings parallel to the beds are filled with quartz. Here, too, numerous joints are observed striking parallel to the axis and dipping generally about 20° N. or 20° S., in this respect resembling those mentioned in describing the Old Eureka opening.

The mill equipment includes two roofing slate shanties, two school slate saws, and the usual trimming saws, planers, and rubbing beds. An accessory mill serves for polishing only. In 1928 the quarry was operated by the Slatington Slate Company, which took it over in 1917 and has operated it continually since.

Quarry *c* is called the Mountain quarry. Though one opening when its outline at the surface is considered, this is really two separate holes into bed rock, of which the west is a shaft about 60 feet square and the east a larger irregular quarry with maximum dimensions 345 by 150 feet and 150 feet deep. The two together show what might be anticipated from their location with respect to the other quarries just described. In the shaft the anticline of the Eureka quarries alone is seen. In the larger opening, however, work has been extended far enough northward to expose the syncline as well. Here the beds on the north anticlinal limb are seen to be greatly thinned by compression. The synclinal axis appears at the surface 85 feet south of the northwest edge, the Klondike big bed here measuring 18 feet in actual thickness. In addition to quarrying, tunnelling along the strike has been resorted to for working the Upper Star big bed.

The Mountain quarry, though controlled, like the Eureka, by the Slatington Slate Company, was not being worked when last visited in 1927. This company actively operated the two openings between 1901 and 1918, however. The Mountain quarry is said to have yielded 80,000 squares of roofing slate.

54. *Pittston Quarries.* These two openings are about 200 feet east of the east edge of the Mountain quarry. In size they are similar, being about 375 by 100 feet and roughly 200 feet deep. Though of similar dimensions, they are "staggered" with respect to the regional strike. The west opening thus barely reaches south to the outcrop of the Upper Star big bed, whereas the east quarry extends well beyond it. Both show the southerly anticline and the more northerly syncline. The Klondike big bed appears in neither of these openings on account of the west pitch of the syncline, as described on pages 27 and 279 and illustrated in Figure 8 and the structure section (Plate 56). The Lower and Upper Star big beds, however, are both accessible in these openings.

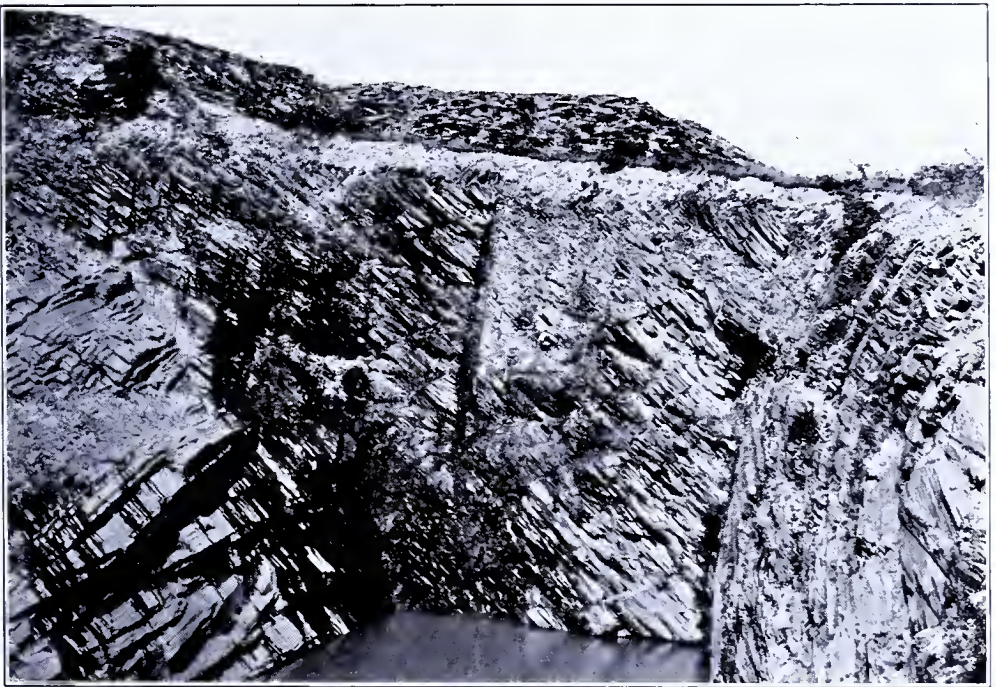
No equipment remains at either quarry and both seem to have been long abandoned.

55. *East Berlin and nearby Quarries.* These are located east of the road which leads between the Blue Ridge quarries on the east and the Carbon, Old Columbia, and Old Berlin quarries on the west. Two are close together and just east of the road mentioned. These are com-

PLATE 59.



A. Anticline of Eureka quarry, from middle of southwest side; note jointing, which is approximately horizontal.



B. Looking at northeast wall of eastern Peters Quarry, north of Emerald, to show Franklin "run;" the Lower Franklin big bed is to the south, the Upper Franklin on the north edge of the opening.

monly called the East Berlin openings. About 400 feet east of these are three irregular openings, long abandoned and with no traditional names.

The East Berlin openings are both partly filled with waste. The west one is 55 by 175 feet in size and shows 20 feet of slate above the water with which it is filled. The strike is N.67°E. and the dip 73° to 80°N., being steeper along the north edge. In the east opening the beds strike and dip similarly. Both quarries expose the two Washington big beds.

The three irregular openings mentioned are all small, even the middle one, which is the largest, being only 75 by 20 feet in size. This latter shows 20 feet of slate above water level. The beds strike N.65°E. and dip 60°N.; cleavage dips 45°S. One big bed, thought to be the Lower Franklin but not conclusively correlated by measurements, is seen.

Structurally these five openings are similarly situated, on the north limb of an anticline. They have all been long abandoned and nothing is known of their history.

56. Two old, deserted openings are situated about 1400 feet due north of the east Hughes quarry, on the north side of Trout Creek. The eastern opening is roughly triangular and about 140 feet on the side. In it the beds strike N.60°E. (?) and dip 14°S., whereas the cleavage strikes N.70°E., dips 45°S. Measurements of two big beds appearing here serve to correlate them with the two Washington big beds. The suggestion is that this quarry is on the south limb of an anticline.

The west opening is larger, with maximum dimensions of 140 by 170 feet. A little slate appears in the northwest side, where the two big beds seen in the east quarry are visible, but elsewhere the bed rock is hidden by waste.

These quarries were opened and operated by Joel Neff, and later by Caskey and Emack. The later history is not known.

57. *Penn Lynn Quarry.* This opening, lying just northwest of the highway at the west edge of Slatington, is 190 by 275 feet in size. It is said to be 150 feet deep but is now filled with water. Sanders¹ gives the cleavage as striking N.80°E., dipping 40°S., and the beds N.80°E., 60°S. The quarry is thus on the south limb of a synclinal fold. It is believed that the beds worked here included the Lower Washington big bed and the Penn Lynn "run." Between 1904 and 1910 this quarry was worked by the Slatington Slate Company. Nothing more is known of its history.

58. Three openings east and southeast of the Cambridge quarry are grouped together under this number. The two southerly ones are 500 feet north of the Penn Lynn quarry just described. Of these, the west hole is 100 by 60 feet in size and 30 feet deep. It shows only a small amount of heavily weathered slate on the west side of the opening. The more easterly of these two quarries is separated from that just described by a 20 foot bridge of rock. It is about 90 by 100 feet in size and of irregular shape. Its total depth is estimated at 75 feet but it is now filled with water. A little slate shows, the beds striking

¹ Op. cit., p. 115-116.

N.80°E. and dipping vertically, whereas the cleavage strikes N.70°E. and dips 50°S. Structurally the opening is thus seen to be north of an anticlinal axis. It was operated for a time by the Carbon Slate Company, working in the Franklin "run."

The north quarry of these three is about 600 feet east of the Old Cambridge quarry. It is 170 by 80 feet in size and exposes 90 feet of slate on the southeast side. Here the beds strike N.70°E. and dip 27°S., whereas the cleavage has a parallel strike and dips 75°S.; the strata are thus rising northward toward the crest of the anticline which is south of the Cambridge syncline. One big bed, probably one of the Keystone big beds, shows in the bottom of the opening. Nothing is known of the history of operations here.

59. *Blue Ridge Quarries.* These two openings are about 1200 feet northwest of the National School slate Company's mill and roughly a mile due east of the Rextown crossroads. Eastward from them in turn lie two large quarries, the Pennsylvania-Star and the Old Cambridge.

The Blue Ridge quarries include a large westerly opening and a smaller hole in which operations were just beginning in 1927. The west opening is now abandoned; a serious cave-in of slate and overburden on the southeast side ended operations some years ago. It measures 225 by 275 feet at the surface. An exceptionally heavy cover of glacial till (see Plate I, A) lies above the bed rock, necessitating extensive stripping which extends from 25 to 50 feet back from the edge of the opening on all sides.

Some 90 feet of slate are exposed above water level. At the northwest side the beds strike about N.70°E. and dip 28°S. On the southeast side the strike is similar but the dip is 82°S. In both places the cleavage strikes N.70°E. and dips 64°S. These surface observations are consistent with the structure seen in the northeast wall of the quarry, for this exhibits a syncline the axial plane of which emerges 125 feet south of the north corner and strikes and dips like the cleavage. As remarked elsewhere, the cleavage planes radiate downward in the trough of the fold.

The quarry is opened in the two big beds of the Star "run." The Lower Star big bed just reaches the quarry bottom in the trough of the syncline. The axis here appears to pitch west only very slightly and probably assumes an eastward pitch still farther west, to judge by areal relationships.

The quarry hole operated at present has a depth of 120 feet and surface dimensions of 85 by 125 feet. It shows the south limb of the northward tipped syncline exposed in the larger quarry, for the beds at the surface dip 80°S., and in the bottom at the northwest edge they dip 55°N. Cleavage strikes N.75°E. and dips 67°S. Grain trends N.37°E. and dips 82°E.

Many joints are observed, with strikes parallel to the strike of the cleavage and north or south dips that are rarely in excess of 45°. The joints of this south synclinal limb flatten strikingly to the south and steepen northward. They are the loci of considerable weathering which takes the form of "rusting." Jointing is most marked in the larger beds.

The beds worked are again the two big beds of the Star "run." School slate is made from some of the darker beds. A measurement of the sequence in this quarry is presented in Plate 39.

Equipment includes two mills, one for making school slate (the National School Slate Company's mill) and the other, situated southwest of the old quarry, for making roofing slate and some school slate; the plan of the latter mill is given in Figure 31.

Most of the production from this quarry goes to the factory of the National School Slate Company, the largest school slate producer in the United States. This is located on the west outskirts of Slatington, north of Trout Creek.

60. *Old Cambridge and Pennsylvania-Star Quarries.* These two openings are directly northeast of the Blue Ridge quarries along their strike continuation. The west opening was once worked as two separate operations, the westerly being the Pennsylvania and the easterly the Star, from which the Star "run" is named. This measures 235 by 350 feet, is roughly rectangular, and largely filled with waste. In the bottom the syncline described in connection with the Blue Ridge quarry is seen. Pre-glacial erosion, however, has cut so deeply that the Upper Star big bed just shows in the bottom of the synclinal trough. Cleavage strikes $N.70^{\circ}E.$ and dips $62^{\circ}S.$; this observation also defines the attitude of the axial plane. The axis pitches $6^{\circ}W.$ in this quarry.

The east opening is the Old Cambridge quarry. It is smaller than the Pennsylvania-Star, measuring 350 feet in the northwest direction by 125 feet. The depth is about 120 feet. The Cambridge syncline described at the Blue Ridge and Pennsylvania-Star quarries is best seen here, due to the fact that pre-glacial erosion has not gone as deep as it has farther west. This structure is well shown in Figure 47. Both Star big beds are well exposed. At the south end beds at the surface dip vertically, whereas the dip along the northwest side is $30^{\circ}S.$, with a strike of $N.74^{\circ}E.$ The axial plane of the fold reaches the surface near the middle of the quarry. The syncline pitches $4^{\circ}W.$, and along the trough quartz and calcite-filled joints strike $N.40-50^{\circ}E.$, and dip $30-40^{\circ}N.$

Interest attaches to the amount of thickening of the beds in the trough of the fold. Thus, the Lower Star big bed is $13\frac{1}{2}$ feet thick at the axis, 12 feet thick 50 feet (measured on the bed) from the axis, and 11 feet thick, 85 feet from the axis. Similarly, the Upper Star big bed is 28 feet thick at a point 20 feet north of the axis, but only $22\frac{1}{2}$ feet thick an equal distance south of the axis, though it is 33 feet thick in the axis. It is thus seen that there is not only considerable thickening near the fold axis, but that the thinning is more conspicuous on the south than on the north synclinal limb.

Not only has open quarrying been carried on here, but a tunnel has been driven northeast on the Upper Star big bed.

No data are available as to the time when this quarry was opened, but Sanders¹ mentions it in his report for which the field work was done in 1880. The quarry was worked by the Cambridge Slate Company of Slatington between 1897 and 1912, since when it has been idle, the company having developed its shafts to the north instead.

¹ Op. cit., p. 116, 1883.

61. *Cambridge Shafts.* Three small shafts, each about 30 by 50 feet in surface area, lie just south of the Ridge Road, some 2000 feet northwest of the Slatington post office and 100 feet apart. The east shaft is 195 feet deep; the two westerly ones show the same dimensions; they are reported to be 220 and 225 feet deep, but were not being worked and were therefore inaccessible in 1927.

At the surface in the east shaft the beds strike N.70°E. and dip 27°S., whereas the cleavage strikes like the beds and dips 82°S. In its descent the shaft passes through the Upper Franklin big bed and, after traversing 29 feet of "ribbed" slate, it encounters the Lower Franklin big bed, here 23¼ feet in actual thickness. In the shaft this bed strikes N.80°E., dips 11°S. It is followed northward by a tunnel (see Figure 6) 275 feet long in 1927. Whereas the tunnel remains horizontal for some distance north of the shaft, the bed continues to rise, until its top is above the roof of the tunnel. This is at a distance of 175 feet from the shaft. Beyond this point, however, the beds dip northward and the tunnel now is driven on a slope so as to follow the dip of the bedding, which averages about 17°N for 100 feet, where the "breast" was located at the time when this field work was done. The fold with crest as described appears to pitch west at a gentle angle.

The cleavage strike is N.71°E., and the dip is 85°S. Jointing is common. The fractures are of two sets, one virtually horizontal, the other striking N.70°E. and dipping 35°N. Locally these latter shatter the slate greatly, making the underground operations hazardous.

The width of the tunnel-incline is about 100 feet parallel to the strike. In breaking the rock neither drilling nor broaching are resorted to, only explosives. Two accessory pulleys are used for hauling large blocks out to the shaft from the "breast."

Surface equipment includes a mill, roofing slate shanties, a storage shed (Plate 18, A) for roofing slate, a boiler house, and a good blacksmith shop. The three shafts have been operated since 1912 by the Cambridge Slate Company. They represent true underground mining of slate.

62. *Blue Diamond Quarries.* These three old openings, the east of which is now used as the Slatington garbage dump, are all just north of the Lehigh Valley Railroad spur leading from Slatington to the Eureka quarries. The two west openings are 1400 feet northwest of the Cambridge shafts, and the east quarry, commonly called the Blue Diamond, is an equal distance north of the shafts mentioned. For convenience they may be lettered *a*, *b*, and *c* from the west eastward.

Quarry *a* is 100 by 75 feet in area and shows 12 feet of slate above water. Cleavage is seen to strike N.70°E., and to dip 60°S., but no beds are recognizable.

Quarry *b* is 100 by 65 feet in size and shows 12 feet of slate above water level. The beds strike N.70°E. and dip 80°S., whereas the cleavage strikes N.68°E. and dips 42°S. Two big beds show in the southwest side, each 15 feet thick and separated by 30 feet of slate.

The two openings are probably situated on the north slope of an antiline tipped to the north. The two big beds described may well be the First and Second Locke big beds.

The Blue Diamond quarry is 95 by 140 feet in surface dimensions,

roughly rectangular, and shows about 10 feet of slate on the northeast side. Here the beds are essentially horizontal, but on the southwest side a small exposure has beds dipping 13°S. , with a strike of $\text{N.}85^{\circ}\text{E.}$ Cleavage strikes $\text{N.}80^{\circ}\text{E.}$ and dips vertically. This quarry is thus a little south of the antilinal crest mentioned at Quarries *a* and *b*. Some quarrymen maintain that the beds once worked are in the Franklin "run," but this interpretation the writer cannot accept. Rather it seems more reasonable, though proof cannot be established, to assign this sequence to a stratigraphic position between the Lower Star and the Uppermost Locke (Manhattan) big beds.

Nothing is known of the history of any of these quarries.

63. *Thomas and Roberts Quarries.* Three openings lie north of the road connecting the Eureka quarries with Welshtown or Slatington, and about 1750 feet east of the Pittston quarries.

All are small, the eastmost pit being 110 feet in diameter, the north opening 50 by 30 feet, and the west one 90 by 110 feet. Though all are filled with water, none is believed to exceed 80 feet in depth.

The east opening shows no bed rock in place. In the north quarry a little slate is seen, having cleavage that strikes $\text{N.}70^{\circ}\text{E.}$ and dips 58°S. , but bedding could not be determined. The southwest hole shows a little slate of which the cleavage strikes $\text{N.}72^{\circ}\text{E.}$ and dips 50°S. , but there is, at best, only a faint suggestion of beds (dip $65^{\circ}\text{S.}?$). Tentatively the Eureka syncline and the anticline to the north are believed to separate the west and east openings from that to the north.

The southwest opening was successfully worked for school slate in the years near 1900. No other significant data as to the history of these operations are available. All are now on the property of Robert Roberts of Slatington.

64. This long abandoned opening is in the stream bottom near the railroad spur that leads to the Eureka quarries, about a mile northwest by rail from the Slatington station. It is 65 by 115 feet in plan and was probably never very deep. Water now fills it nearly to the surface. A little slate shows locally, with cleavage striking $\text{N.}70^{\circ}\text{E.}$ and dipping 30°S. , but bedding is very uncertain. There is also no basis for correlation with the beds of other quarries.

65. *Stelz Quarries.* These two openings lie north of Welshtown and 0.6 of a mile north of the Slatington post office. The west opening is the Old Welshtown quarry. It is 145 by 165 feet in surface dimensions. It has a large dump and was evidently deep, but is now filled with water and no slate is seen. Sanders¹, who visited it about 1880, reports that it showed two big beds, a lower one of 27 feet and an upper of 18 feet, separated by 25 feet of thinner beds; these measurements are all taken on the cleavage surfaces and therefore of comparative value only. These are probably the Keystone big beds. Their structural relations are not given.

The east quarry is a small hole about 700 feet southeast from the last. It is 30 feet square. The beds strike $\text{N.}65^{\circ}\text{E.}$ and dip 85°S. , whereas the cleavage strikes parallel but dips 70°S. , hence the structure here is the north limb of an anticline tipped to the north. A 10-

¹ Op. cit., p. 115, 1883.

foot bed, thought to be the Lower Star big bed, outcrops here. Recently this hole has been enlarged by the Hankee Brothers with a view to developing more slate.

66. Three openings are located on the west side of the railroad between Welshtown and the Slatington station. For convenience they may be designated *a*, *b*, and *c*, beginning at the north. None is now being worked and their histories are not known.

Quarry *a* is 120 by 80 feet in surface area and shows 30 feet of slate above the water which fills it. The beds strike N.70°E. and dip 57°S.; cleavage strikes N.70°E. and dips 47°S.; grain trends N.30°W. A series of joints which strike N.40-70°E. is seen, dipping 25-45°N. One big bed, estimated to be about 11 feet in actual thickness, crops out in the southwest side of the quarry. As it was inaccessible, it could not be correlated with certainty, but may represent one of the Keystone big beds, here appearing on the north limb of a northward-tipped anticline.

Quarry *b* measures 100 by 65 feet in surface area and shows above water level 20 feet of slate with curved cleavage. The beds strike N.70°E. and dip 46°S., whereas the cleavage strikes N.70°E. and dips 38°S. Joints similar to those described in Quarry *a* are seen, striking about N.60°E. and dipping 0-40°N. Two big beds, the upper 6 feet, the lower 7½ feet thick, are exposed, but their correlation could not be established. The structural relations are as in Quarry *a*.

Quarry *c* is only a prospect, 20 by 65 feet in size. There is one big bed, but the bedding is too poorly marked to make measurement possible. The cleavage strikes N.80°E. and dips 18°S.

67. *Welshtown Tunnel and East End Quarries.* East of the railroad spur connecting the Eureka quarries and Slatington, on the hill about 2700 feet northwest of the Slatington station, is a group of three openings in the slate. That on the west slope of the hill, at about road level, in the little settlement called Welshtown, is a true tunnel. It leads into the hillside, N.75°E. along the strike of the bedding. It could not be explored, because now full of water, but measurements show that the big bed on which it is driven is the Lower Franklin, which here dips 12°S., whereas the cleavage strikes N.83°E. and dips 78°S. The structure is thus the south limb of an anticline. The history of the Welshtown tunnel is not known; it was made prior to 1880, for Sanders mentions it in his report¹ and it is said by some to have been opened as early as 1844.

About 300 feet northeast of the Welshtown tunnel, at the top of the hill, is an irregular opening 100 by 150 feet in size. In it the beds strike N.70°E.; they dip 25°S. at the north edge, but flatten to 12°S. at the southeast side, suggesting the approach of a synclinal axis (probably the Cambridge syncline) to the south. The cleavage strikes N.80°E. and dips vertically. The beds worked here include the Upper and Lower Franklin big beds and the intervening thinner layers. An interesting feature is the presence at the south end of the opening of a small thrust fault which follows the cleavage plane in part and passes into a small fold at depth (see Figure 78).

The third quarry of this group is an opening 400 feet east of the

¹ Op. cit., p. 115, 1883.



A. Northwest side of west opening of Gennine Washington quarry, showing tunnel operations; the right tunnel is partly clouded by steam from quarry operations.



B. Overburden at East End quarry, consisting of glacial drift, partly stratified.

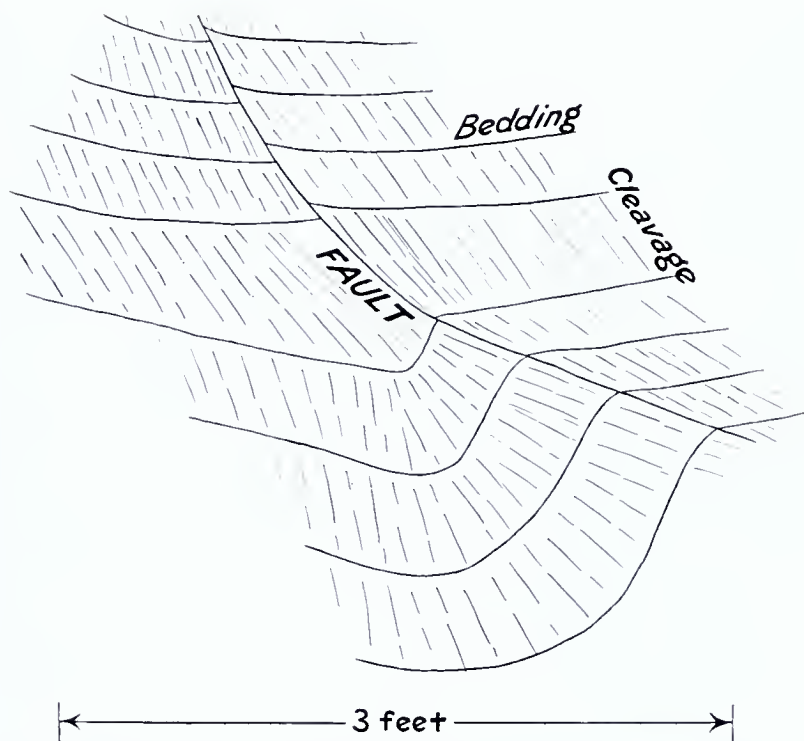


Fig. 78. Small fault, mainly along cleavage, passing into a drag fold; old hillside quarry (No. 67), north of Welshtown tunnel.

last, operated in 1927 by the Slatington Slate Company, but subsequently shut down. This is the East End quarry. It is 100 feet in diameter and 110 feet deep.

Here the slate is covered by 40 feet of overburden (see Plate 60, B.), showing some assortment and evidently of glacio-fluvial origin. This heavy cover of loose material necessitates extensive bratticing and adds to the expense and danger of operating. At a depth of 95 feet the bottom of the Lower Franklin big bed is encountered. Here the bedding strike is $N.78^{\circ}E.$ and the dip $18^{\circ}S.$; the cleavage strikes $N.85^{\circ}E.$, dips $65^{\circ}S.$, and the grain trends $N.38^{\circ}W.$ The structure is thus similar to that in the Welshtown tunnel. The beds are badly shattered with closely spaced joints striking $N.70-80^{\circ}E.$ and dipping south at angles of less than 45° . It is of theoretical interest to note that the acute bisectrices of these joint planes or of the joint planes and bedding planes taken together are essentially horizontal.

A tunnel leads north from the shaft some 50 feet along the Lower Franklin big bed, which was being worked in 1927.

This quarry is equipped only for making roofing slate; the customary mill, saw tables, and shanties are located west of the opening.

68. This small, unnamed quarry is about 500 feet north of the Welshtown tunnel (Quarry 67) and east of the road from Slatington to Welshtown. It is only 30 feet square and shows 20 feet of heavily weathered slate above water level. The beds strike $N.75^{\circ}E.$ and dip $75^{\circ}N.$, whereas the cleavage strikes similarly and dips $68^{\circ}S.$; the structure is thus the north limb of an anticline, probably the same

fold the south limb of which shows in the quarries numbered 67. The beds in this opening should be above the Franklin "run" if the interpretation of the local structure is correct.

Nothing is known of the history of operations here. The quarry must once have been much larger than now, for a good-sized dump and mill are nearby.

69. *Fullmer and Keystone Quarries.* These two openings are between the Lehigh Valley Railroad and the highway that leads from Slatington to Lehigh Gap. The south opening, approximately 1400 feet north of the station at Slatington, is the Fullmer quarry; the northern or Keystone quarry is about 300 feet farther north.

The Fullmer quarry is 250 by 200 feet in area; the large dump to the south suggests that its depth is at least 100 feet and probably more, but water now fills it to ground level. Along the northwest side the beds are virtually horizontal. Near the middle of the northeast side the beds strike about $N.70^{\circ}E.$ and dip $13^{\circ}S.$, but they probably turn sharply a short distance south of the opening, as exposures southward along the railroad exhibit beds dipping $55^{\circ}S.$, whereas cleavage dips south more gently. Structurally therefore, the Fullmer quarry lies immediately north of a synclinal axis, probably the Prudential syncline.

The beds here worked are generally known as the Fullmer "run," but are nowhere found in quarries that are now operating and therefore were not measured in detail in the course of this work. Most of those seen on the walls of this opening are thin, but one big bed, having an estimated thickness of 12 feet, outcrops a little south of the quarry and was probably reached with depth.

The detailed history of the Fullmer quarry is not known. It was already opened when Sanders visited the region and is one of the oldest quarries of the district. It has been long abandoned.

The present opening of the Keystone quarry is 110 by 130 feet in size. It is 40 feet to water level, of which 20 feet are stratified drift like that described at the East End quarry. The opening was once much deeper, but is now largely filled with waste.

One big bed (the Lower Keystone) is seen in the walls, striking $N.71^{\circ}E.$ and dipping $26^{\circ}S.$; here the cleavage strikes $N.80^{\circ}E.$ and dips $60^{\circ}S.$, indicating that the beds are not overturned and hence that the structure is continuous with that in the Fullmer quarry, the south limb of an anticline. The southward-dipping beds of the Keystone quarry pass under those of the Fullmer opening and are stratigraphically beneath them.

South of the big bed mentioned and therefore stratigraphically above it is another, the Upper Keystone. This is not now visible, having been removed almost completely by quarrying.

The equipment still in place consists of an old mill building from which the machinery has been largely removed. The history of the Keystone quarry reaches back well into early slate development at Slatington, for it is one of the first quarries to be operated on a large scale. The original hole was much larger and mainly south of that now seen.

70. *New York Tunnel.* Extensive underground mining was carried

on in what is reputed to be the Penn Lymm "run" beneath the Washington beds, about 1400 feet west of the Slatington railroad station. This tunnel includes at least some 400 feet of accessible work but more of it is now filled with water and inaccessible. It develops a big bed on both sides of a small anticline, hence follows along the crest of this structure in a westerly direction from the portal. The same bed is said to have been quarried through a shaft which lies 150 feet northwest of the tunnel portal, and is now covered with waste.

Near the mouth of the tunnel the beds strike $N.65^{\circ}E.$ and dip $17^{\circ}N.$; these observations are north of the anticline axis mentioned as appearing in the tunnel. South of the axis, in the mine, the beds dip gently south.

Here also there has been some quarrying in the hillside, and several open cuts remain. A school slate factory was operated between the tunnel portal and the railroad, but was burned down some years ago.

71. Two abandoned openings lie between the Lehigh Valley Railroad and the Slatington-Lehigh Gap highway about half a mile north of the railroad station at Slatington. The north hole is 90 by 65 feet in size and filled with water so as to show no slate in place.

The south opening is a cut with two tunnels, at different elevations on the hillside, just east of the highway. This quarry with its tributary tunnelling is of irregular shape and measures roughly 80 by 60 feet. The cut and tunnels show a sequence of beds that is readily correlated with the Franklin "run"; the Upper Franklin big bed appears in the open cut and the lower tunnel affords access to the Lower Franklin big bed. In general, the strike is $N.80^{\circ}E.$ and the dip $18-31^{\circ}S.$, whereas the cleavage strikes $N.83^{\circ}E.$ and dips variously $65-90^{\circ}S.$ A minor, sharp drag fold shows in the southwest side of the quarry. The structure therefore is the south limb of an anticline, the crest of which is indicated by the fold of the Lower Franklin big bed in the highway cut 250 feet north of the opening here described.

This quarry is now abandoned. It was last worked by the Franklin Big Bed Slate Company, but the years of operation are not known.

72. *Lehigh Gap and Bill Hughes Quarries.* These two openings are just west of the Slatington-Lehigh Gap highway, about one mile north of the railroad station at Slatington.

The south opening is the Bill Hughes quarry. It is roughly rectangular and measures 100 by 70 feet in plan, showing 50 feet of slate on the southwest side above the water which it contains. At the southeast side the beds are horizontal, but at the northwest side they strike $N.57^{\circ}E.$ and dip $62^{\circ}N.$, flattening again still farther north to horizontality. The opening thus shows the emergence of a rounded anticlinal crest, with a synclinal axis to the north. Cleavage (and the axial planes of these two folds) strikes $N.68^{\circ}E.$ and dips $67^{\circ}S.$ One big bed estimated to be 25 feet thick, is seen in the southwest wall, but detailed measurements do not furnish a definite basis for correlation. From areal and structural considerations, the strata here should lie beneath the Franklin "run." The synclinal and anticlinal axes emerging are probably equivalent to the Eureka syncline and to the anticline to the south, also seen in the Eureka quarry.

The northern of the two openings here described is the Lehigh Gap quarry. This lies 250 feet west of the highway. It is 100 by 125 feet in size and shows 60 feet of slate along the northwest edge. Water stands in the bottom. In the south corner the beds strike $N.65^{\circ}E.$ and dip $35^{\circ}S.$; northward they rise to a sharp anticlinal crest (see Figure 79),

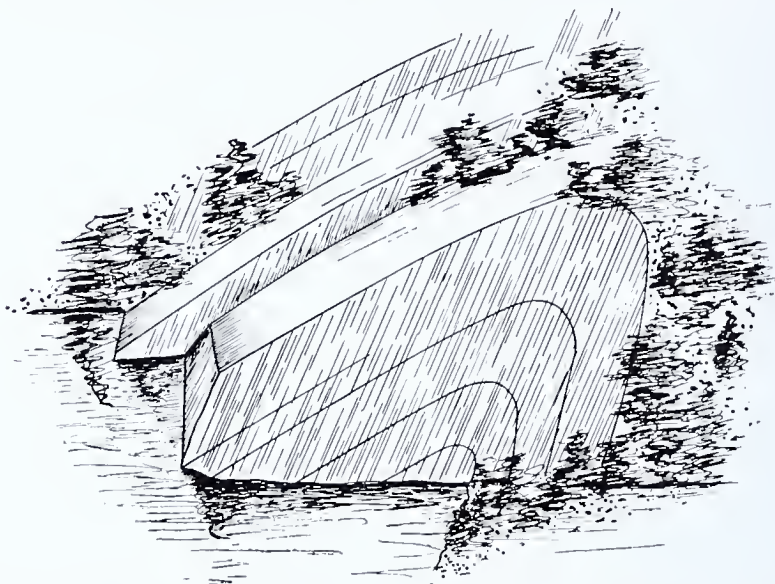


Fig. 79. Sharp anticline, with northward overturning, as seen in southwest wall of Lehigh Gap quarry. Width shown about 30 feet.

beyond which, at the north edge of the opening, they strike $N.70^{\circ}E.$ and dip $70^{\circ}S.$, whereas the cleavage dips $55^{\circ}S.$ The axial plane of the anticline thus defined strikes $N.63^{\circ}E.$ and dips $63^{\circ}S.$ This fold is probably the eastward continuation of the one anticipated from observations at the north edge of the Blue Valley quarry.

The strata seen here include three big beds,—an uppermost one 4 feet thick, followed downward in order by 7 feet of “ribboned” slate, 6 feet of a big bed, 15 feet of “ribboned” slate, and 8 feet of another big bed. This sequence does not correspond to any measured by the writer. By quarrymen the beds are said to correspond with those of the Heimbach and nearby quarries (Nos. 79, 81, 82, 83 and 84) east of Lehigh River; but the position of the beds in these eastern quarries with respect to the stratigraphic column for the region as a whole is itself uncertain. From areal and structural considerations these beds would also seem to lie below the Franklin “run.”

The quarry was last operated in 1924. An old mill building still stands on the dump east of the opening.

73. Lucerne Quarry. This opening lies about 700 feet east of the Bill Hughes quarry, on the west side of the Lehigh Valley tracks. It is 120 by 170 feet in size and roughly rectangular; quarrymen estimate its depth at 1000 feet. The hole is now filled with water, and no bed rock is visible. It is said to contain the same fold as was seen in the Bill Hughes quarry and to have opened the same beds, including one big bed, the Heimbach, which did not reach the surface but was encountered at depth. The ruins of an old mill are seen to the northeast. The quarry was worked between 1902 and 1905 by James Kern.

74. *Riverside Quarry.* This is 700 feet east of the Lucerne quarry, 600 feet east of the Lehigh Valley Railroad, and presumably on the strike continuation of the Lucerne opening. It is 80 by 115 feet in size, and shows a little gravel but no bed rock above the water with which it is filled. It is said by Mr. James Kern of Slatington to have about the same depth as the Lucerne opening. The Heimbach big bed occurred here also, as was to have been expected, but was not worked. The structure was anticlinal with two small crests separated by a smaller trough at the top of the larger anticline which appears in this and the Lucerne opening. Nothing is known of the history of Riverside quarry.

75. An old hole, long deserted and probably little more than a prospect, is located 800 feet south of the vehicular bridge across the Lehigh River near Lehigh Gap, two miles north of the Slatington railroad station, and 275 feet west of the highway, on the sloping hillside. Slate blocks and chips and an old building are here, but no bed rock is seen in place. No information could be obtained about the geology or history of this opening.

76. *Caskey and Emack Quarry.* This abandoned opening is 400 feet south of the street connecting Walnutport and Slatington, 200 feet north of the Penn Keystone Knitting Mills in Walnutport. It is 80 feet square and estimated to have been 75 feet deep but no slate is seen, for water and waste fill the opening. The Washington "run" was opened here, according to reputable quarrymen, by Caskey and Emack several years ago.

77. An old, long abandoned opening is located 850 feet north of where Main street in Walnutport crosses the tracks of the Central of New Jersey Railroad. It is 150 by 140 feet in size and a large dump nearby suggests a depth of at least 75 feet. This seems to be the slate quarry which Sanders described as abandoned and full of water in 1880¹. It is believed to have been on the Keystone beds which, in view of its position essentially along the strike of the Keystone quarry, is probably correct.

78. This is an old, long abandoned cut in a gully about 4500 feet north of the Central of New Jersey Railroad Station. It shows only rubble.

79. *West Brensinger Quarries.* These two small shafts lie east of the Lehigh River and west of the highway from Walnutport to Lehigh Gap, about 5000 feet north of the Walnutport station. Both are small, the eastern being 125 feet and the western 80 feet square. Neither shows slate at the surface but merely a heavy overburden of clay and gravel. They are said to have been opened in beds of the Heimbach "run" (see Quarry 84), which here stood vertical, probably on the south limb of a closely folded syncline, believed to be the eastward continuation of the Eureka syncline. They were last operated by L. F. Brensinger of Allentown. Their earlier history is not known.

80. An old, long deserted opening lies 800 feet southeast of the last. It is essentially a cut in the hillside, 30 feet in diameter, and shows

¹ Sanders, R. B., op. cit., p. 112, 1883.

23 feet of slate in the southeast wall. The lower part of the quarry is filled with water. The beds strike N.75°E. and dip 55°N. The cleavage strikes N.80°E. and dips 43°S. Grain trends N.30°E., dips vertically. The structure is clearly the south limb of a syncline, but the correlation of the beds could not be established. The slate on the dump is of good quality. The history of operations here is unknown.

81. *David Williams Quarry.* This and a small opening, presumably a shaft, are indicated as one quarry on the small scale map, because very close together. They lie just east of the Walnutport-Lehigh Gap highway, 250 feet east of the Brensinger quarries. The west opening is only 30 feet square and filled with water, no slate showing. Like the two quarries west of it, it was worked last by L. F. Brensinger of Allentown.

The larger, eastern opening is of very irregular shape and measures 190 by 410 feet, being greatly elongated in an east-west direction. It shows very little slate at the surface, and is filled with water. On the northwest side there is a suggestion of bedding striking N.70°E. and dipping 40°S.; cleavage seems to strike parallel to the beds but dips vertically. The structure here, therefore, seems to represent the north limb of a syncline, and it is at least probable that an anticlinal axis lies near and just beyond the south edge of the opening. Almost certainly the beds are the same as those opened by Quarries 82 and 83, namely a part of the so-called Heimbaeh "run."

This large opening probably represents what was originally two separate holes. Sanders found both in operation in 1880. At that time the east one (properly the "David Williams" quarry) was just being opened. The west one or "Williams and Jones" quarry yielded material for slate pencils; at the south side of this opening "a roll is shown," presumably the crest of the antiline inferred above¹.

82. *Peters Quarry.* This irregular opening, also called the Owen Williams quarry, is situated 75 feet east along the strike from the quarry just described. It is 200 by 240 feet in size, and shows 10 feet of glacial drift and 10 feet of weathered slate above water level. Bedding is not recognizable; the cleavage dips south. Structure and stratigraphy are probably identical with those reported for Quarry 81.

This quarry was worked in the early 80's for roofing and school slate. One bed 8 feet thick was especially profitable. After being opened by Owen Williams it passed into the hands of the E. D. Peters Company.

83. *Rudolf Quarries.* Two smaller openings are situated about 200 feet east of the last, and along the eastward strike continuation. Of these the western is an irregular hole, 120 feet on each side, now largely filled with waste. In the west corner a thickness of 8 feet of slate shows above the water which stands in the quarry. Here the beds strike N.80°E. and dip vertically, the cleavage dipping about 55°S.; northward the beds flatten slightly, clearly approaching a synclinal axis.

The eastern opening is about 120 by 175 feet in size and filled with water. A little slate shows above water level on the west edge, displaying a flat syncline, which has an axial plane that strikes N.80°E. and

¹ Sanders, R. H., op. cit., p. 112, 1883.

dips 70° S.; the north limb has by far the gentler dip and the beds are correspondingly less compressed.

These two openings were made about 1880 by the Griffith Brothers Slate Company. They were not a success, probably because of the close folding and consequent crumpling of beds. Operations were stopped in 1893.

84. *Heimbach Quarry.* This large opening is about 1.2 miles northeast of the railroad station at Wahnport and 400 feet east of the Rudolf quarries described above. It is roughly circular in shape, with a diameter of about 260 feet. Slate shows locally above the water with which the quarry is filled but exposures are poor and the dip of the bedding is too variable to furnish positive evidence as to the structure. The cleavage strikes $N.75^{\circ}E.$ and dips steeply south. Slate seen on the waste heap has excellent splitting qualities parallel to the cleavage and seems to hold its color well.

The quarry was operating in 1880 and is described by Sanders¹. The wall showed an anticlinal axis emerging a little north of the southeast edge. At the bottom of the quarry and near the northwest edge, a synclinal fold appeared and would presumably outcrop a short distance north of the opening. The largest bed—probably the Heimbach big bed of quarrymen, also mentioned at quarries 72, 73, and 74, west of the Lehigh River—is described as measuring 10 to 15 feet in thickness or 25 feet along the cleavage. At the time of Sanders' visit roofing slate was the chief product but a large school slate factory was located here also to use some of the darker beds.

There is much question as to the correlation of the strata exposed here, as well as in the Rudolf, Peters, and David Williams quarries nearby, in the Lehigh Gap, Bill Hughes, Lucerne, and Riverside quarries west of Lehigh River and in Quarry 85, yet to be described. The beds in these quarries are collectively spoken of as the Heimbach "run," and the big bed described by Sanders is frequently mentioned and was of prime economic importance. Structural relations and geographic distribution suggest that the Heimbach "run" is immediately above or below the Franklin "run," but openings are lacking where the sequence can actually be measured, and north of the Hower quarry at Danielsville, well above the Star "run," are two big beds thought by some to be the Heimbach "run," and hence much higher.

The writer can offer only a very tentative correlation; this assigns the Heimbach beds to a position just below the Franklin "run" and seeks to correlate the Heimbach big bed with the Little Franklin big bed, which has a comparable thickness (12 to 14 feet where measured by the writer). The two big beds north of the Hower quarry are, on this hypothesis, correlated with those of the Columbia "run" and are much higher in the stratigraphic column.

85. This is a group of five small unnamed openings, the nearest of which is 300 feet east of the Heimbach quarry; all are south of the Lehigh & New England Railroad. The three southern openings (lettered *a*, *b*, and *c*, from west to east) are essentially on the same strike line. The two others are respectively 200 (Quarry *d*) and 600 feet (Quarry *e*) north of Quarry *c*. None has been worked in recent years.

¹ Op. cit., pp. 111-112 and figure 10, p. 119, 1893.

Quarry 85 *a* is an irregular opening, about 150 by 100 feet in maximum dimensions. At its north edge the beds strike N.80°E. and dip vertically, whereas the cleavage dips 60°S. A small, very tight antiline (see Figure 80) shows here, with the north limb surprisingly thick in



Fig. 80. Small antilineal drag fold in east wall of Quarry 85 *a*.

comparison with the south limb. At the south edge of the opening the strike is as elsewhere and dip is 60°N. Broadly considered, therefore, the structure is antilineal, with minor synclineal and antilineal drag folds, the small fold mentioned above being an example. The major antiline, on the north limb of which this quarry is located is probably the antiline that appears near the south side of the Eureka and Pittston quarries.

Quarry *b* is a deep opening 100 feet in diameter, showing the beds dipping vertically.

Quarry *c* is a shaft, 50 feet in diameter and about 100 feet deep to water level. In its walls the cleavage strikes N.80°E. and dips 75°S.; the beds appear to be horizontal, probably because near the antilineal crest. Much of the slate on the dump shows fracture cleavage, associated with the close folding of this locality.

Quarry *d* is a roughly rectangular opening, measuring 100 feet on the side, now largely caved. The beds dip gently (20-30°) south, apparently rising to another antilineal axis.

Quarry *e* is a small hillside cut near the railroad; it shows 20 feet of slate in the walls. Two beds each 5 feet thick, with sandy lower edges, are seen, separated by 2 feet of ribboned slate. They strike N.75°E. and dip 25°S., whereas the cleavage strikes N.75°E. and dips 50°S. The structure is thus like that in Quarry *d*.

Nothing is known of the history of any of these openings.

Quarry 86. This small prospect pit lies about 2000 feet east of the Caskey and Emack quarry (No. 76) on the hillside overlooking Walnutport. It is a cut 60 by 40 feet in size and 20 feet deep, filled with decayed and broken slate. It shows thin, sandy beds which strike

N.72°E. and dip 50°S., whereas the cleavage, striking similarly, dips 40°S.; the structure is thus clearly the north limb of a northward-tipped anticline. Smaller pits nearby show no bed rock in place. Evidently none of these openings produced slate on a commercial scale.

Quarry 87. Larrabee Quarries. These three openings are about 1.2 miles east of Walnutport and 2000 feet south of Apps. They are arranged roughly in a line trending north. The south one is 75 by 60 feet in size, probably 60 feet deep, and shows one big bed, 8 feet in actual thickness, which is stratigraphically between the Trout Creek and Washington "runs." The bedding strikes N.62°E. and dips 65°S.; cleavage strikes N.65°E. and dips 26°S. This quarry was opened in 1915 by W. M. Benninger of Berlinsville.

The next quarry north is a large, irregular opening, 200 by 75 feet in area and showing 40 feet of slate above the level of the water that stands in the hole. The Upper Washington big bed comes to the surface in the west corner, and the Lower Washington is seen farther south in the southwest wall. In the west corner the beds strike N.58°E. and dip 71°S.; cleavage strikes N.55°E. and dips 40°S. Much of the slate shows false cleavage. No equipment, other than one old shanty, remains. The opening was made about 1915 by a Pittsburgh operator.

A small pit, 50 feet square, is seen in the stream bottom north of the last quarry described. It shows only a little till, for water fills the opening. Its history is like that of the quarry last described.

88. Benninger Quarries. These two opening lie about 1.2 miles northeast of the Walnutport railroad station. Each is about 40 feet square. The walls of the east quarry are so completely overgrown with vegetation and so badly slumped that dependable observations of structure could not be made. The west quarry shows 25 feet of weathered and fresh slate above the level of standing water. Here the beds strike N.63°E. and dip 60°S.; since the cleavage dips only 46°S., it is clear that the beds are on the south or overturned limb of a syncline. They are probably in the Williamstown "run."

These two quarries were last worked in 1912 by W. M. Benninger.

89. Oak Hill and Loretto Quarries. These two quarries are situated about 200 feet east on the strike from the Benninger quarries, on the north bank of Bertsch Creek. The west or Oak Hill opening is 90 by 80 feet in area and shows 35 feet of slate above the water level, being probably 50 feet deeper yet to quarry bottom. The beds here strike N.57°E. and dip 70°S.; the cleavage strikes N.62°E. and dips 37°S. The Lower Williamstown big bed, 10½ feet in actual thickness, appears at the middle of the southwest side and the Upper, 7 feet thick, is seen near the northwest edge. The structure is evidently the north limb of an anticline tipped to the north, just as in the Benninger quarries. Operations here were carried on with Pittston, Pa., capital; they were discontinued about 1915.

The east (Loretto) quarry is 90 by 110 feet in size and shows 40 feet of slate above the level of the water, which stands at the surprising elevation of 20 feet above the stream, although the latter is only 150 feet away. The structure and stratigraphy are as in the Oak Hill quarry the dip decreasing slightly toward the north. Noteworthy horizontal

joints cut the thicker beds. This quarry was operated by a Wilkes-Barre company at about the same period as the Oak Hill quarry and was shut down at the same time.

90. This opening is about 700 feet east of the Loretto quarry, on the north bank of Bertsch Creek, near the stream. It is a small cut in the hillside, 30 by 100 feet in area and 20 feet deep, showing thin beds of slate that strike $N.57^{\circ}E.$, and dip $43^{\circ}S.$, with cleavage striking $N.60^{\circ}E.$ and dipping $75^{\circ}S.$, hence it is on the south limb of an antiline. The exact stratigraphic position of these beds is doubtful. The history of operations here is not known.

91. *Old Griffith Quarry.* This is located about a quarter of a mile northeast of Apps, in a field some 400 feet north of the Lehigh & New England Railroad. It is a rectangular opening, 115 by 50 feet in area, with 18 feet of slate showing above water level. The beds strike $N.80^{\circ}E.$ and dip $85^{\circ}S.$ Cleavage strikes $N.80^{\circ}E.$, dips $50^{\circ}S.$ Grain trends $N.30^{\circ}W.$ and dips $75^{\circ}NE.$

One big bed, $9\frac{1}{2}$ feet thick, is seen near the northwest edge of the opening; it is believed to be the Upper Star big bed, but the only evidence for this correlation is in the areal and structural relations, as identifying measurements could not be made. The slate on the dump is of fair quality, but shows some rusting and false cleavage.

Operations were by the Griffith Brothers Slate Company between 1888 and 1893.

92. *Peters Quarries.* At and near Berlinsville is a group of 17 quarries, indicated on the sketch map (Figure 81). The west two of these

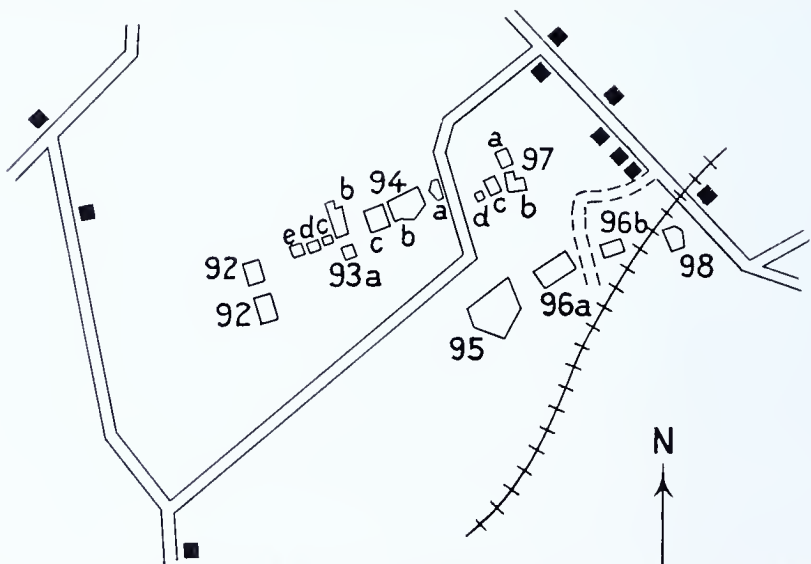


Fig. 81. Sketch map to show numbers and letters used to designate the quarries at Berlinsville.

openings lie in a north-south line on the hillock east of Apps. They are both roughly circular, 70 feet in diameter, and probably 80 feet deep, but water now stands in them.

In the north opening the Upper and Lower Franklin big beds, here 11 and 10 feet thick, respectively, are seen striking $N.72^{\circ}E.$, dipping

68°S. at the surface and steepening slightly downward. Cleavage strikes N.67°E. and dips 45°S. Grain trends N.35°W., dips vertically. This quarry is structurally south of a synclinal axis.

At the southeast end of the south opening the beds strike as in the other but dip 3°N., whereas the cleavage strikes N.75°E. and dips 45°S. Hence the beds here are not overturned. Farther north along the walls, however, they take a sharp turn, dipping 70°S. There is thus near the middle of the opening an anticlinal axis, which has an axial plane similar to the cleavage in strike and dip, namely, N.62°E., 53°S. A slight eastward pitch of the axis is indicated.

One big bed, about 7 feet in actual thickness, is seen near the middle of the opening. This is the Little Franklin big bed.

These quarries were worked by E. D. Peters several years ago, but are now abandoned. No equipment remains in place.

93. *Hughes and Griffith Quarries.* Within 600 feet east of the Peters Quarries, just described, are five openings, of which the north four are on the line of strike from each other, while the fifth is a little to the south (see Figure 81). For convenience they are designated by letter as indicated on the key map.

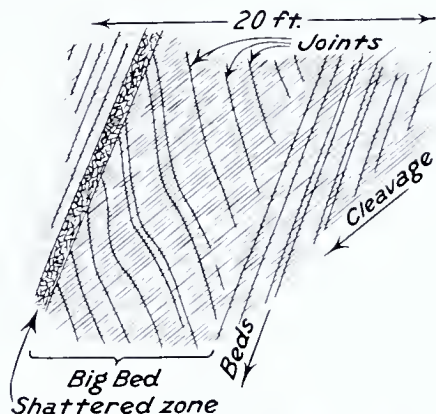


Fig. 82. Sketch of shattered zone in association with Upper Franklin big bed in Quarry 93 b; note relation of sigmoidally curved joints.

Quarry *a* is approximately circular in plan and 80 feet in diameter and is 35 feet deep. It is opened in the Little Franklin and associated beds. On account of the surface decay and inaccessibility the structure is uncertain.

Quarry *b* is east along the strike from the northern of the two Peters quarries. It is 75 by 200 feet in size and represents extensive operations. Along the southeastern edge the beds generally strike N.61°E. and the dip is 58-75°S. at the surface but steepens downward. The Upper and Lower Franklin big beds are seen, as well as the Mammoth big bed, which is 58 feet above the Upper Franklin and 12½ feet thick. At the south (lower) edge of the Upper Franklin big bed is an open, crushed zone, about a foot wide, evidently representing a bedding slip zone. From it numerous gently sigmoid joints pass north and down into the Upper Franklin big bed. Much the same feature is also seen in this quarry under the Lower Franklin big bed. These shattered zones are probably not true bedding slip faults, as there is little or no evidence that they have cut out individual beds, but there has unquestionably

been a breaking free of the big beds along their sandy bottoms and a certain amount of post-cleavage movement along the parting planes thus defined (Figure 82).

Quarry *b*, together with Quarry *a*, was last worked by Lamb and Ditchett of Bangor.

Quarry *c* is 70 feet deep and 60 feet square. It shows the same structural relations as Quarry *b*, but is opened along the Lower Franklin big bed, not having been carried far enough north to encounter the Upper Franklin.

Quarry *d* is 80 feet deep to water level and 60 feet square. It, too, exposes the Lower Franklin big bed, along which in the east and west walls tunnels have been driven. This and Quarry *c* were last worked by David Hughes.

Quarry *e* was opened by George Griffith. It is 125 by 100 feet in ground plan and shows 70 feet of slate above the waste which covers the bottom. Here the beds strike N.68°E. and dip 67°S.; cleavage strikes N.65°E. and dips 40°S. The same two big beds of the Franklin run are present. The structure and stratigraphy are thus like those in the quarries on both sides.

94. *Peters-Atlas Quarries.* These three larger openings are east along the strike from the quarries numbered 93. They are lettered from east to west, *a* to *c* (see Figure 81).

Quarry *a* is a small opening, 90 by 80 feet in area, showing 5 feet of waste slate above water level. No data are available as to this opening.

Quarry *b* is 270 by 250 feet in maximum size, is of irregular shape, and has a total depth of 45 feet to water. It shows beds striking N. 72°E. and dipping 73°S. at the bottom, but flattening upward. The cleavage strikes similarly but dips only 39°S. The structure is thus the south limb of a syncline that is tipped northward, resembling, as might be expected, that of the more northerly of the Peters, Hughes, and Griffith quarries.

Quarry *c* is 200 feet by 235 feet in size, of irregular form, and 70 feet deep to the level of the water which stands in the hole. At some 50 feet (horizontal distance) north of the southeast edge, the Little Franklin big bed is seen. The two Franklin big beds are also opened near the middle of the northeast wall. Even the Mammoth big bed (see also Quarry 93 *b*) shows in the northwest edge.

The beds generally strike N.72°E. and the dip averages 70°S.; the cleavage dips more gently. The structure is thus the north limb of an anticline, just as in Quarries 92 and 93.

These three openings were made by the Atlas Slate Company about 1905 and later worked by the E. D. Peters Slate Co., but are now abandoned.

95. *Provident Quarry.* This large opening is about 0.3 mile west of the station of Berlinsville on the Lehigh & New England Railroad (see Figure 81). It measures about 325 by 425 feet in area and has a depth to water of 40 feet, but is doubtless at least 100 feet deeper.

The quarry shows the south limb and trough of the Prudential syncline. The southeast edge of the opening is along the Lower Washington big bed, and near the middle of the quarry the Upper Washington outcrops with a dip of 75°N.; this flattens downward so that at water

level the bed dips only about 45° N. There is even a faint suggestion at the northwest edge of the opening that the beds are rising somewhat to the north. The axis of the syncline thus defined, therefore, appears at water level near the northwest edge of the opening. Like the cleavage it strikes $N.70^{\circ}E.$ and dips $60^{\circ}S.$ (See Figure 83).

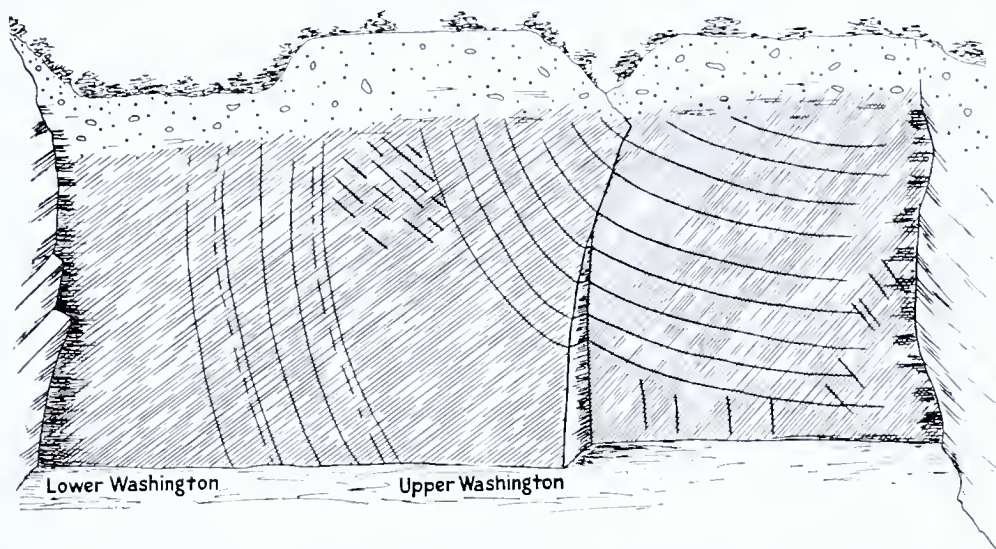


Fig. 83. View of southwest wall of Provident quarry at Berlinsville. Note the two Washington big beds, the synclinal structure, and the pronounced thickening downward of the Upper Washington big bed.

When visited in 1927, the Provident quarry was idle, though there was some probability that it might be reopened, as operations have in the past been highly successful. Some finished roofing slate was still on the landing. A large roofing slate mill is near the quarry.

96. *Genuine Washington Quarries.* These are two quarries east about 200 feet along the the strike from the Provident quarry, and showing essentially the same beds and structure.

The west opening (Quarry *a* of this report and "Quarry 2" of the operating company) is 225 by 200 feet in size and about 190 feet deep. As in the Provident quarry, the base of the Lower Washington big bed forms the southeast wall. At this edge the beds, covered by 40 feet of glacio-fluviatile overburden, strike $N.72^{\circ}E.$, and dip vertically. In their descent they flatten slightly, then steepen again, and once more flatten somewhat in approaching the trough of the main (Prudential) syncline. Cleavage strikes $N.72^{\circ}E.$ and dips $40^{\circ}S.$ Grain trends $N.18^{\circ}W.$ and dips $80^{\circ}NE.$

The work in the bottom is proceeding along two tunnels (Plate 60, A) which are driven in the northwest wall down the dip of the Upper Washington big bed. The eastern tunnel is sufficiently inclined so as to expose a part of the Lower Washington big bed as well. In the face where the tunnels are driven the beds have not yet attained the horizontal attitude seen in the Provident quarry, but dip about $22^{\circ}N.$ Fracture cleavage is seen locally, and there are also prominent joints, striking $N.75^{\circ}E.$ and dipping $30^{\circ}N.$

The east opening (Quarry *b* of this report) is 65 by 110 feet at the surface and 180 feet deep. It shows the same structure as Quarry *a*:

the beds on the southeast side strike N.65°E. and dip 70°S., but in the bottom they dip about 40°N. Cleavage and grain are as in Quarry *a*. In the bottom a tunnel has been driven north to quarry the Lower Washington big bed. Flat joints, dipping 15-50°N. and called "floors" by the quarrymen, are conspicuous in the big bed.

These two openings are equipped with the customary mill for making structural slate and blackboards. An interesting feature is the substitution of derricks with booms of the type used in Maine, in place of the cableways commonly seen in the Pennsylvania slate regions. Broaching has also found favor in these quarries.

These two openings were long worked by A. P. Berlin of Slatington and his associates, but are now in the hands of the Amalgamated Slate Quarries Company of Easton, Pa. In the Slatington region they were in 1927 the only two actively operated quarries east of Lehigh River.

97. *Atlas Quarries.* There are four of these openings about 300 feet north of the Provident quarry. The north one (Quarry *a*) is a roughly circular hole, with a diameter of about 55 feet. It shows some 40 feet of weathered slate in the walls. The beds strike N.70°E. and dip 85°S., whereas cleavage strikes N.75°E. and dips 57°S. The Mammoth big bed is seen near the north wall, and the Upper Franklin big bed shows near the south edge.

The next opening (Quarry *b*) to the south is almost continuous with Quarry *a*; it measures 150 by 50 feet and is roughly L-shaped in outline. The structure is like that in Quarry *a*. The Lower Franklin big bed outcrops in the middle of the northeast wall.

Quarry *c* lies west of *b*. It is 160 by 120 feet in plan and shows 50 feet of slate above the water standing in the bottom. Cleavage strikes N.70°E. and dips 45°S. Grain trends N.36°W. The Lower Franklin big bed appears near the middle of the wall, striking N.80°E. and dipping 85°S.

Quarry *d* is 50 feet west of *c* and 30 feet square. It is a shallow pit and shows only some weathered, thin beds. Structurally all of these openings are north of an anticlinal axis which lies between them and the Provident quarry.

The dump built up east of these quarries shows some good slate. An old mill, still equipped with machinery, stands here.

These openings are said to have been made by the Atlas Slate Company about 1895. Subsequently the property was purchased by A. P. Berlin but the quarries were shut down at the beginning of the war. They now belong to the Amalgamated Slate Quarries Company of Easton, Pa.

98. *Roberts Quarry.* This lies 400 feet east of the eastern Genuine Washington quarry (No. 96 *b*). It is 125 by 150 feet in areal dimensions and filled with water, a heavy glacial overburden, at least 20 feet thick, appearing on the sides. No slate is seen above water level. It is said that this quarry was carried to a depth of 240 feet and showed essentially the same structure as the Genuine Washington quarries, the beds dipping steeply south at the surface and steeply north farther down, with a progressively flattening northward dip.

This quarry was opened in 1920 by the Michael J. Roberts Slate Com-

pany, and shut down in 1925. Slates seen on the dump are of good quality.

99. *Hahn and Griffith Quarries.* These are situated 1600 feet north of the Berlinsville Station on the Lehigh & New England Railroad. The western pit measures 130 by 60 feet and shows only glacial till, in part stratified, above water level. The eastern opening is 50 feet in diameter and filled with water. These are little more than prospect pits, opened by Granville Hahn and the Griffith brothers.

100. *John Benninger Quarry.* This small opening, 800 feet east of the last, is 110 by 70 feet in size and 25 feet deep to water level. The beds strike $N.72^{\circ}E.$ and dip $50^{\circ}N.$ at the southeast edge, but the dip becomes $72^{\circ}N.$ with depth and shows a similar change in going northward at the surface. Cleavage strikes $N.76^{\circ}E.$ and dips 70° or less south. From these facts the inference may be drawn that there is an anticlinal axis to the south, probably not far from the quarry. Correlation of beds could not be established.

This opening is on the property of John Benninger. It has not been operated recently. Slates seen on the dump are of fair quality.

101. This small opening is about 1000 feet east of the last. It is 15 by 30 feet in size, and clearly only a prospect. Beds strike $N.80^{\circ}E.$ and dip $35^{\circ}S.$; cleavage strikes $N.75^{\circ}E.$ and dips $60^{\circ}S.$ The beds are thus not overturned, but represent the south limb of an anticline.

102. *Seybold Quarry.* This small pit is 800 feet north of Quarry 101, and is 60 by 100 feet in size and 8 feet deep to water level. Cleavage here strikes $N.62^{\circ}E.$, dips $60^{\circ}S.$; bedding is not distinct but seems to strike $N.60^{\circ}E.$ and dip $35^{\circ}N.$ A correlation of the strata could not be established.

The Commonwealth Slate Company operated this quarry from 1922 to 1926.

103. *Prudential Quarries.* These lie about 0.9 miles east of the Berlinsville Station of the Lehigh & New England Railroad, and just north and west of the turn in the highway leading from Berlinsville to Danielsville. The western is a small opening 75 by 85 feet in area, and now filled with water, so that only 4 feet of weathered slate are exposed. One big bed, probably in the Penn Lynn "run", is seen. The bedding strike is $N.72^{\circ}E.$ and the dip averages $70^{\circ}S.$ Cleavage strikes $N.80^{\circ}E.$ and dips $35^{\circ}S.$ Grain trends $N.18^{\circ}W.$

A much larger opening, properly the Prudential quarry, lies east of the last. It measures 300 by 230 feet in area and was once about 150 feet deep, though now filled with water. At the surface the beds dip $70^{\circ}S.$, much as in the smaller opening. Though inaccessibility prevented confirmation by the writer, the Lower and Upper Washington (at the south end) and the Little Franklin, Lower Franklin, and Upper Franklin big beds are all reputed to have appeared in this quarry, dipping steeply southward (it is said, $50-60^{\circ}$) on the north, overturned limb of an anticline.

Other regional considerations indicate that a synclinal axis must lie a short distance north of the main Prudential quarry, hence the name

of the quarry has been given to this prominent fold, which can be followed from the east to the west end of the district.

The Prudential quarries are said to have been shut down about 1920. Shanties, boiler house, office, and masts are still standing.

104. A small opening lies in a field about 800 feet east of the Prudential quarries. It is only 20 feet square and now filled with water. No bed rock is seen in place, but a little split slate, which is somewhat sandy, is found on the dump. There is general agreement among competent quarrymen that the Lower Washington big bed comes to the surface in the walls of this opening. However, the pit is only a prospect hole and never produced commercial slate.

105. *Banner Quarry.* This is located just west of the Berlinsville-Danielsville highway, 2500 feet north of the Prudential quarries. It is a rectangular opening 300 feet square, and full of water, but with 25 feet of slate showing on the east and west sides. The cleavage is clearly shown, striking $N.68^{\circ}E.$ and dipping $48^{\circ}S.$ Jointing produces curved planes dipping steeply north, and easily confused with bedding. A close study of the east wall, however, shows the bedding, striking $N.71^{\circ}E.$, dipping $50^{\circ}S.$ This is an average figure, but the strata actually show numerous drag folds, and at the southeast edge of the opening they dip only about $20^{\circ}S.$, the cleavage being horizontal.

From these relations between bedding and cleavage, it is clear that the structure is the south limb of a syncline, tilted to the north.

Of interest is the appearance in the middle of the northeast side of a chloritic, graphite-free bed, the Gray bed of the Hower quarry. This can be followed eastward through this part of the Slatington region, and probably lies just under the Lower Star big bed.

This quarry was opened by B. Maurer about 1880. It was then bought by the Banner Slate Company, which operated it between 1902 and 1914, and still owns the property. An old mill building is south of the opening. A little slate is still seen on the dump and is of fair quality, though showing false cleavage.

106. *Oplinger Quarry.* This opening, situated 1400 feet northeast of the Banner quarry, is L-shaped, with maximum dimensions of 70 and 145 feet. In the wall at the southeast side, about 15 feet of slate are seen above water level. Here the beds strike $N.58^{\circ}E.$, dip $51^{\circ}S.$ Cleavage strikes $N.60^{\circ}E.$, dips $29^{\circ}S.$ This suggests the north limb of a northward-tilted anticline. Grain trends $N.28^{\circ}W.$

Nothing is known as to the history of this quarry.

107. *Madoc Quarry.* This moderate-sized opening, 150 by 225 feet in area, is 1000 feet east of the Oplinger quarry. The bottom is filled with water. Below 5 feet of glacial till some weathered slate shows, with cleavage striking $N.65^{\circ}E.$ and dipping $40^{\circ}S.$ No bedding is recognizable, but it is reported that the beds dip gently south.

The Madoc quarry was opened about 1897 by the Madoc Slate Company. It is now idle. A mill building stands on the waste dump to the east.

108. *Pearl (York-Lien) Quarry.* This is located about 1700 feet east of the Oplinger quarry. It is 240 by 100 feet in size; the depth

is uncertain, as water stands in the bottom. The beds strike N.80° E. and dip 20-25° S.; cleavage strikes N.70° E., dips 60° S. These relations indicate the south limb of an anticline axis, probably that which lies south of the Oplinger quarry.

No big beds are seen, but the Gray Bed exposed in the Banner quarry is said to outcrop 40 feet north of the Pearl quarry.

The history of this quarry is linked with that of the Madoc quarry to the east.

109. West Montgomery Quarry. This large slate quarry is half a mile east of Edgemont crossroads. It measures 240 by 350 feet in plan, and is filled with water, but shows about 12 feet of slate above water level along the sides. The depth attained is said to have been 100-120 feet.

At the southeast side the beds strike about due E., dip 30° S. Here the cleavage strikes N.65° E. and stands vertical. The grain trends N.-35° W. The Gray bed, also seen in the Banner quarry and possibly to be correlated with the Gray bed of the Albion "run" at Pen Argyl, outcrops near the middle of the southwest side. In view of the relations between bedding and cleavage, it seems probable that the structure here is the south limb of a westward-pitching anticline.

This is one of the few quarries of the Danielsville region where "ribboned" roofing slate was made. Some such slate is still seen on the dump east of the quarry. The quality is good, though some "cats-paws" and knotty slate are seen. There is no mill on the property but shanties, boiler house, blacksmith shop, masts and cables still stand.

Quarrying was begun here in 1895, the small hole to the east (see Quarry 111) being the first one opened. Several partnerships in succession controlled production, and in 1908 the property was enlarged. Since the war production has been sporadic, and in 1927 the quarry was idle.

110. A small pit, 50 feet square lies about 600 feet southeast of the West Montgomery quarry. No slate shows in the opening.

111. East Montgomery Quarry. This is situated 400 feet east of the larger West Montgomery quarry. It is 150 by 180 feet in surface dimensions and is filled with water, so that no geologic observations could be made. It is probable, however, that the bottom of a shallow, westward pitching synclinal axis, not mapped because the evidence is controversial, repeats the Lower Star bed here, the strata dipping south near the north end of the opening and oppositely near the south end.

For the equipment and history of this quarry the reader is referred to the description of the West Montgomery quarry.

112. Haynes Quarries. Three old openings, long deserted, are about 300 feet southeast of the East Montgomery quarry. The west hole is completely filled with water. It is about 125 by 175 feet in area. Of the two easterly holes, the northern is 80 by 120 feet in size, and is also filled with water to the surface of the ground. The southern opening is 80 by 115 feet in size and shows only a small amount of heavily decayed slate at the surface.

In the absence of observational data, it may be assumed from re-

lations to the nearest exposures that these quarries are opened near a synclinal trough in beds between the Star and Franklin "runs."

Nothing is known of the history of these operations.

113. East Haynes Quarries. Two small openings, only 50 feet apart, are located in a field 1600 feet east of the quarries numbered 112. The north, main quarry is 160 by 60 feet in size, and largely filled with water. Its beds strike N.75°E., dipping steeply south. There is a strong suggestion here of a nearby fold axis, for at the southeast side the dip is 85°S., whereas it is 70°N. at the north edge. One bed about 8 feet thick (probably one of the Keystone big beds) appears near the middle of the quarry. The cleavage strikes N.65°E. and dips 35°S. The beds are thus on the north limb of an anticline, showing northward overturning, with a synclinal axis not far to the north. The slate seen on the dump seems to be of good quality, but shows some conspicuous jointing.

The small hole to the south is only 50 feet square. It shows the same structure as the larger opening, excepting that the dip of bedding is steeply south throughout.

These quarries have not been worked since 1917.

114. Williams Quarry. This is 600 feet northeast of the East Haynes Quarries and about an equal distance west of the Danielsville-Berlinsville highway. It is 80 by 140 feet in size, full of water, and shows no slate in place, though good pieces, not closely ribboned, are on the dump. The slate blocks seem to show conspicuous close jointing.

The quarry was opened in 1865 by Owen Williams and later (1902-1910) operated by the same company that developed the Haynes and East Haynes quarries.

115. Armiento Quarry. This small opening is a little less than half a mile north and west of the East Haynes quarries, between the two branches of the Lehigh & New England Railroad west of Danielsville. It is 120 by 50 feet in areal dimensions. What appears above water level is only decayed slate and glacial drift, so that no inferences can be drawn as to structure and succession of beds. The history of operations is also unknown.

116. Continental Quarry. This lies just southeast of the Berlinsville-Danielsville highway, about a mile in direct line south of Danielsville. It is 180 by 90 feet in areal dimensions. Being filled with water to the surface, it shows no bed rock. Its history is said to be linked with that of the Williams quarry (No. 114).

This opening should be in beds between the Franklin and Star "runs" and the walls, if visible would probably show a poorly marked synclinal trough.

117. Wales-Bangor (Federal Slate Company) Quarry. This abandoned slate quarry is 1000 feet north of the Continental quarry. It is approximately 125 feet square and filled with water. Some slate shows, however, the beds striking N.65°E. and dipping vertically, whereas the cleavage strikes N.70°E. and dips 45°S.; these relations suggest the north limb of an anticline, tipped northward. Chips on the dump

show fragments of the Gray bed, hence the strata lie between the Franklin and Star "runs".

Operations here have been in many different hands, and the property is still owned by an operating company, but has lain idle for several years.

118. This deserted quarry is about half a mile east of Bassards Corners, just south of the road. It is roughly circular and 55 feet in diameter. Some twenty feet of slate, without overburden, are seen above water level. No big beds were noted, and the thinner ones exposed are not stratigraphically identifiable but are believed on reputable authority to be in the Williamstown "run". The beds strike N.-45°E., dip 85°S., whereas the cleavage strikes N.70°E. and dips 38°S., relations which indicate the north limb of a westward pitching anticline.

This quarry was last operated by J. E. Oplinger about 1910.

119. *Sewell Quarries.* Two openings, close together, about 1.1 miles south of Danielsville, are situated in a field south of the highway. The north opening is 140 feet on each side and about 60 feet deep. The slate beds strike N.55°E. and dip 60°S., whereas cleavage strikes N.75°E., dips 35°S. Two big beds, those of the Franklin "run", show in this opening.

The south quarry is 40 feet deep and slightly smaller than the other. The bedding dips 55°S., the cleavage 35°S. The structure here, then, as in the quarry to the north, is the south limb of a syncline. Two big beds, the Upper and Lower Washington, are seen, the Lower big bed appearing a little north of the south edge of the opening.

These quarries were first operated by the Sewell Slate Company and later for a time by J. K. Hower of Danielsville. At present they are idle.

120. East along the strike some 600 feet from the Sewell quarries are three openings in the stream bottom, which may be lettered *a*, *b*, and *c*, beginning at the north.

The northmost (Quarry *a*) is about 180 feet square and shows directly in the stream bottom. Its total depth is probably not more than 50 feet below stream level. Here the beds strike N.50°E. and dip 65°S., steepening upward as though approaching an anticlinal crest above and to the south. Consistent with this hypothesis, the cleavage strikes N.55°E. and dips 38°S., that is, more gently than the beds. This opening is in the Washington "run", the Upper and Lower big beds and the intervening ribbons corresponding fairly well in thickness and sequence with standard sections.

Quarry *b* is about 300 feet south of the last. It shows a high west wall in the stream bottom. In this the beds strike and dip as in Quarry *a*, but perhaps slightly steeper; the cleavage dips 35°S.; the structure is thus as in Quarry *a*. The beds opened here are probably in the Trout Creek "run".

Quarry *c* is still farther south along the stream. It is 60 feet square and 50 feet deep. The beds and cleavage strike and dip as in Quarry *b*. One conspicuous bed about 12 feet thick, probably the Upper Blue Mountain big bed, is exposed near the northwest side.

Down stream from the quarries described there are also several smaller pits in the hillside east of the stream.

As to history, the two north quarries were opened by the Hower Brothers Slate Company and the south pit was last operated by the Empire Slate Company. All are now deserted.

121. North of the quarries numbered 120, and in the creek bank immediately south of the first road crossing the stream, is a small pit 120 by 100 feet in area and roughly rectangular in plan. Some 10 feet of slate show here, the cleavage striking N.60°E and dipping 50°S. The bedding and correlation could not be established but the Lower Washington big bed, dipping gently south and thus lying north of a syncline is reputed to have been quarried.

This hole was opened in 1870 by Charles Henry.

122. *Parry Quarries.* Four small openings lie north of the quarry just described and of the eastward road, and 800 feet east of the highway to Danielsville. The northern three openings are in an east-west line and may be lettered *a*, *b*, and *c*, going eastward; the south quarry (*d*) is the largest and lies due south of Quarry *b*.

Quarry *a* is a small, triangular opening, 80 feet on each side, in which a little slate shows above the water. Here bedding strikes N.15°W. and dips 23°S., whereas cleavage strikes N.70°E. and dips 68°S. Grain trends N.15°W. From the relations between cleavage and bedding here exhibited, it is plain that this opening is on the axis of a westward pitching anticline, probably the one inferred to lie south of the Banner quarry.

Quarries *b* and *c* are both small pits now filled with waste. Quarry *d* is about 125 feet in each surface dimension, and shows a little slate above water level, covered by 10 feet of till. The beds here strike N.85°W. and dip 25°S., cleavage strikes N.65°E. and dips 50°S. The structure is thus on the south limb of the anticline mentioned above as passing through Quarry *a*.

These are old workings, now deserted, and none is of economic importance today.

123. *Hower Quarry.* This, the largest quarry near Danielsville, is about 3500 feet south of the Danielsville crossroads. It is about 525 by 500 feet in area and of irregular shape. Unfortunately only a little slate shows above water level, but the original opening is said to have been about 300 feet deep. The absence of good exposures is especially regrettable since this quarry is located in a critical position for interpreting both the structure and the stratigraphy of the region.

At the northeast side the beds strike N.70°E. and dip 65°S.; cleavage strikes N.75°E. and dips 40°S. The structure is thus on the north limb of an anticline tipped northward. This is the only place where definite evidence as to structure is available now. Competent observers, however, report that near the bottom the strata turned, so as to outline a synclinal trough, an interpretation supported by observations near the Banner quarry.

The beds exposed are said to have included the Gray bed mentioned at the Banner, Wales-Bangor and other nearby quarries. The writer believes, on the basis of measurements, that the Upper Franklin big

bed would appear just southeast of the opening; similarly the Lower Star big bed should be in the northwest edge.

The finished roofing slates still on the dump are of good quality, though many show false cleavage. An old mill building, a transformer house, and masts still stand on the dump, but the quarry, operated even earlier than 1880, was idle and dismantled in 1927. It really represents the fusion of three large openings of which the northern was the Eagle, or original Hower quarry.

124. Gem Quarries. Two smaller openings, about 1200 feet north of the Hower quarry and east of the highway, are both filled with water. The larger, northern one is 90 by 175 feet in size and shows a synclinal axis, which, like the cleavage, strikes about $N.65^{\circ}E.$ and dips $60^{\circ}S.$ The smaller, southern pit is 125 by 80 feet in size and exposes no slate, being filled with water. These beds are inferred to be in or above the Columbia "run," from a consideration of the structures and the known outcrop of lower beds, especially the Gray bed, to the south.

Some quarrymen contend that south of the Gem quarries a trench exposed the Heimbach "run," with two big beds. This the writer questions, as pointed out on page 323, contending that stratigraphic position of the Heimbach "run" is below the Franklin beds.

The Gem quarries were first opened in 1857. As late as 1880 they were operated by the Henry Brothers. At present they are idle.

125. Cambria Quarry. This large quarry, also called the Harper, is about 1200 feet northwest of the Gem openings. It is now full of water. Its dimensions are 415 by 225 feet, with a depth said to be 250 feet.

In the north corner, beneath 15 feet of glacial till, the beds are seen to strike $N.62^{\circ}E.$ and dip $70^{\circ}S.$; cleavage strikes $N.60^{\circ}E.$ and dips $40^{\circ}S.$ The structure is thus the north, overturned limb of an anticline. Southward there is a further steepening of dip. It is reported also that at a depth of about 200 feet the beds turn to dip north.

Nothing is known as to the stratigraphic position of the strata exposed. Sanders mentions only thin beds¹. What slate is seen on the dump is of good quality.

This opening was made before the Civil War and is the oldest of the Danielsville quarries. From 1862 to some time after 1880 it was in the hands of Henry Harper, who used the product to supply a large school slate factory then located at Edgemont. Subsequently the quarry changed hands and it is now idle. No machinery remains.

126. National Quarry. This is really two holes, now united, lying about 1200 feet east of the Hower quarry. It is irregular in form, with 375 and 100 feet as the maximum areal dimensions. The depth is unknown and the hole is full of water.

As to structure, the beds at the middle of the northeast side strike $N.45^{\circ}E.$ and dip vertically. Cleavage strikes $N.65^{\circ}E.$ and dips $40^{\circ}S.$ South along the surface the bedding turns slightly so as to tip steeply south. At depth, too, it is said that the beds turn, so as to dip north. These facts suggest the presence southward of an anticline that is tilted to the north.

¹ Sanders, R. H., op. cit., pp. 99-100, 1883.

This quarry is in beds a little older stratigraphically than those of the Hower quarry. The Gray bed is north of the northwest edge of the opening. Measurements even suggest that the Lower Washington big bed occurs in the southeast end.

First opened in 1865, this quarry has been operated and abandoned intermittently. The most recent activity here was about ten years ago; old mill and office buildings still stand on the ground.

127. *Rept Quarry.* This small hole, 40 feet square, is 1500 feet east and across the road from the National quarry. It shows 20 feet of slate in the walls. The beds are indistinct, but seem to strike N.70° E. and dip 65°S. Cleavage strikes N.65°E. and dips 55°S. There is much sandy material on the dump.

Observations at this pit, coupled with its areal position, suggest that it is approximately in the Blue Mountain "run" and is located north of an anticlinal crest. It is little more than a prospect.

128. In the woods about 1500 feet north of the Rept quarry is a small triangular opening, about 110 feet on each side. A little slate shows above water on the southeast side. The bedding could not be determined, but the cleavage dips 35°S., and the opening is probably south of the synclinal axis that lies north of the Hower quarry.

129. This lies 600 feet north of the last and measures about 100 feet square. Though a large dump is nearby, the opening is full of water and structural observations could not be made. The slate on the dump shows sandy facies and numerous "catpaws."

LYNNPORT GROUP.

The quarries of this group are in the valley of Ontelaunee Creek and its tributaries, scattered over an area about eight miles long in a north-east direction and two miles wide, which lies parallel to and south of the top of Blue Mountain, and north of the crest of Shoehary Ridge. Several small towns, including New Tripoli, Lynnport, Wanamaker, and Steinsville are in or near the quarry region, along the line of the Schuylkill & Lehigh (Reading) Railroad. The quarry production could find an outlet over this railroad, either by trucking to the main tracks or by means of railroad spurs; in no case are the openings more than three miles by road from the railroad.

All of the quarries of the Lynnport group are now abandoned. They lie in what the writer believes to be the "soft" or upper slate member of the Martinsburg formation. The structural interpretation of this region has already been discussed (see page 162 et sequor). These slate beds may well be the equivalent of the ones worked at Slatedale and eastward, but the basis for exact correlation is not available.

West of Slatedale the contact between the upper Martinsburg and the sandy middle member suggests the relatively simple structure of repeated, roughly isoclinal folds. At Mosserville, at the eastern end of the Lynnport region, however, there is an abrupt southward bend, suggesting, if the sandy beds north of Mosserville underlie the "soft" slate (an interpretation, it will be recalled, which is generally agreed to by others, but not accepted by Stose), that there is just north of Mosserville an anticline of the sandy layers that pitches west; south

of this fold, between Mosserville and New Tripoli, there appears to be a syncline of the "soft" slate, also pitching west. These two structures give the sigmoid geologic boundary line between the upper and middle members of the Martinsburg that is seen on the geologic map. For a discussion of the detailed observations upon which this structural hypothesis is based, the reader is referred to the description of Quarries 26 and 28 given below. Further, most of the folds west of Slate-dale, at their western exposures, show a slight westward pitch, which is consistent with the westward pitch recognized at Mosserville.

As regards the structure in the Lynnport region it will be recalled also, from the pages referred to above, that a thrust fault (called the Eckville fault) is believed to lie south of the two low "hogbacks" of elliptical ground plan just west of Quaker City and the eastward continuation of the same. This fault is supposed to lift older middle Martinsburg sandstones and slates to the south up and against the younger "soft" slate and immediately subjacent sandstone of the hogback to the north. The south edge of the area of "soft" slate production here described is thus, strictly speaking, bounded not by Shochary Ridge, but by the Eckville fault. It might be added that some doubt exists as to the exact location of this fault in the region west of Quaker City; the question is, is its trace north or south of the "hogback" mentioned above.

In detail, no attempt has been made to carry fold axes for great distances across the region, as the economic unimportance of the quarries did not seem to merit the expenditure of time needed for such more minute studies.

The cleavage in the Lynnport region generally dips steeply south, in places almost vertically. Near the southern edge of the visible occurrences of slate, however, there is observed a marked tendency toward flattening, coupled usually with curvature in the cleavage planes. These conditions are attributed by the writer to the influence of the Eckville thrust fault that is thought to lie to the south; it is believed that the faulting dragged the cleavage from its original vertical into a more nearly recumbent attitude.

False cleavage is fairly general. What has been said elsewhere as to its common occurrence in association with the axes of folds and with curved cleavage is borne out here as well. Jointing has not been carefully studied, but commonly strikes parallel to the cleavage.

Attempts to correlate the beds exposed in the quarries of the Lynnport group with those of the Slatington region have not met with success, partly, perhaps, because this matter received very little attention, partly because of the limited exposures. It is at least possible, however, that the equivalence of the strata in the two regions might yet be definitely established if due allowance were made for changes in relative thickness along the strike. One difficulty is introduced by the fact that the southern edge of the slate belt in the Lynnport region is bounded by the Eckville fault and it is thus altogether likely that some of the lower slate beds have been "cut out."

Though now no longer important, the quarries of this region were once actively worked and contributed materially to the slate production of the State. It is not probable that they will experience a revival in the near future, however. The yield formerly included almost all

types of "soft" slate products,—roofing, blackboards, electrical slate, structural material, and even marbleized slate; there is no recorded production, however, of pulverized or crushed slate, slate pencils, or school slate.

1. *Hemerley Quarry.* This is 0.7 mile west of Quaker City on the north slope of a small hogback-like hill with elliptical ground plan. It is an old cut, now largely filled, in the south bank of the stream. The slate is typical "ribbed" upper Martinsburg. The bedding strikes $N.75^{\circ}E.$ and dips $53^{\circ}S.$; cleavage strikes $N.60^{\circ}E.$ and dips vertically. No conspicuous big beds are exposed. Nothing is known as to quarry history here.

2. *Mammoth Quarry.* This opening is situated about 600 feet east of the last. It is about 40 feet square and probably 40 feet deep, but filled with water. Though no bedding is seen here, some heavy sandy beds in the stream 150 feet south strike and dip as in the Hemerley quarry.

Slate was quarried here in 1866, the product being largely used for flagging.

3. *Oswald Quarry.* This pit is about 200 feet east of the Mammoth quarry. It is very small and probably also so shallow that solid slate was not encountered. Water fills it at present and bed rock cannot be seen.

4. *Quaker City Quarries.* These three openings lie west of a secondary road that leads northwest from the highway at Quaker City. The north pit is small, 30 feet square and 10 feet deep; in it the bedding is uncertain but seems to dip $65^{\circ}N.$, whereas the cleavage dips $85^{\circ}S.$ Some ten feet of weathered slate show on one side.

About 80 feet south of this opening is another, much larger one, measuring 300 by 100 feet. A little slate with curved cleavage shows on the south side. This is the original Quaker City quarry.

Seventy feet west of the last is a hole 40 feet square and perhaps 10 deep, which shows the same structural relations as given for the north one of these three quarries.

Quarrying here has had a long and varied history, but all three holes are now idle.

5. East of the Quaker City quarries, and immediately across the road, is an opening, 225 by 100 feet in size, showing 7 feet of slate above the water with which it is filled. It is opened on an antilinal crest, for at the southeast edge the beds dip $20^{\circ}S.$, but $5^{\circ}N.$ near the north corner. The bedding strikes $N.70^{\circ}E.$ in general. Cleavage planes strike $N.77^{\circ}E.$ and dip $85^{\circ}S.$ No conspicuous big beds are seen. The slate on the dump appears to be of fair quality, but much of it bears closely-spaced calcareous joints.

6. *Centennial Quarry.* This is about 300 feet north of the last. It measures 80 by 300 feet in size and is separated into two parts by a bridge of waste. One big bed appears along the northeast side near the east corner. The strata strike $N.70^{\circ}E.$ and dip $80^{\circ}N.$, whereas the cleavage strike is parallel to that of the bedding and the dip $70^{\circ}S.$ Structurally the opening is thus on the north limb of the anticline seen

in Quarry 5. One big bed shows in the east side. Grain trends $N.28^{\circ}E.$ This and Quarries 5 and 7 were opened about 1850 and last operated in 1905. Roofing slate was the only product.

7. A small prospect pit about 75 feet square is situated about 100 feet south of Quarry 5. It is filled with waste material and water and no slate can now be seen in place.

8. *Pittsburgh Quarry.* This opening is located about 800 feet east of Quarry 5, at the head of a small tributary to Ontelaunee Creek. It is 200 by 50 feet in size and shows 18 feet of slate above water level. The beds strike $N.83^{\circ}E.$ and dip $60^{\circ}N.$; cleavage strikes $N.74^{\circ}E.$ and dips $75^{\circ}S.$ These relations suggest the north limb of an anticline having an eastward pitch, probably the same fold axis as that inferred to lie south of the Centennial quarry. Grain trends $N.20^{\circ}E.$ One big bed, estimated to be about 20 feet thick and probably the same as that described in the Centennial quarry, is exposed in the northeast corner of the opening.

The history of this quarry is much like that of Quarry 6.

9. *Daniels Quarry.* This is half a mile west of Slateville and the western of three openings that lie west of a northward leading road which here leaves the highway between Slateville and Quaker City. It is irregular in shape, measuring roughly 275 by 140 feet in ground plan, and is 125 feet deep. Though filled with water the quarry shows some slate in the sides.

The southwest wall exhibits two folds, of which the more northerly is antilinal. The fold axes are tipped slightly northward, but are nearly vertical and the folds show far more symmetry than usual. Axial planes strike $N.50^{\circ}E.$ and dip steeply south.

Some roofing slate is still lying on the dump. Aside from the not uncommon presence of false cleavage, it is of good quality. The quarry production was also used for structural material, blackboards, and electrical slate. An old mill and other buildings stand nearby.

This quarry was opened in 1872 and last run about 1905 by a Reading firm. Several buildings, including one shanty and one mill, with the usual equipment are still to be seen.

10. Some 200 feet east is a smaller L-shaped opening about 140 by 105 feet in ground plan, with 8 feet of slate showing above water level. The beds are believed to dip $50^{\circ}N.$, but this is uncertain as the bedding is indistinct. Cleavage strikes $N.70^{\circ}E.$ and dips $80^{\circ}S.$ Structurally, therefore, the opening is north of an antilinal crest, the same as the one seen in the Daniels quarry.

The history of this opening is like that of the Daniels quarry.

11. This lies about 100 feet east of Quarry 10 and west of the road leading northwest from Slateville. It is 250 by 120 feet in size and 30 feet of slate show above the water with which it is filled. The beds dip $35^{\circ}N.$ and the cleavage $45^{\circ}S.$, hence the structure is just south of an antilinal axis. The strike of the cleavage is $N.72^{\circ}E.$, and that of bedding is somewhat more northerly.

Slate seen on the dump are of good quality, though the ribbons are unusually closely spaced.

12. *Kalbach Quarry.* This is east of Quarry 11 and also east of the road that leads northwest from Slateville. It is an irregularly rhomboid opening, 200 by 60 feet in plan. Some 35 feet of slate show above water level in the northeast side, and the quarry probably does not extend far below water level as the dump is small. In the northeast wall a sharp syncline shows, the north limb dipping 32° S. at water level, the south limb being overturned, as is usually the case with folds in the soft belt. The fold axis lies somewhat north of the strike continuation of Quarry 11; the anticlinal axis of the latter is thus probably the southward complement of the syncline in the Kalbach quarry. The cleavage strikes $N.80^{\circ}E.$ and dips $84^{\circ}S.$ Since this is the north synclinal limb and the beds strike $N.55^{\circ}E.$, there is clear evidence of a pronounced easterly pitch of the fold. No big beds are recognizable.

This quarry was opened by William Roberts about 1860 and shut down in 1880. It is said to have a tunnel leading eastward along the strike from the northeast wall.

13. *Roberts Quarry.* This is situated about 800 feet east of the last and some 600 feet west of the old church at Slateville. It is about 90 feet square and shows 25 feet of slate above water level. A shallow syncline is exposed, the beds in the south corner dipping $35^{\circ}N.$ The axial plane of the fold, like the cleavage, strikes $N.73^{\circ}E.$ and dips vertically. This is probably the syncline occurring south of the anticline that shows in the Daniels quarry (No. 9).

The slate here is typical soft slate, with broad carbonaceous ribbons. One bed at water level is about 10 feet in actual thickness.

This quarry was opened in 1895 by William Roberts and has been idle since 1901.

14. *North Kistler Quarry.* This is the northern of two openings located about half a mile east of Slateville, on the east side of the road to Blue Mountain. It is 50 by 30 feet in size and filled with water, so that no slate shows at the surface. In the road immediately west of the quarry, however, the beds are seen to dip $50^{\circ}S.$, whereas the cleavage dips $65^{\circ}S.$, the strikes of bedding and cleavage both being about $N.70^{\circ}E.$ The inference is that the structure in the quarry is the north limb of a syncline, probably the one observed in the Kalbach quarry, as the strike continuation of the latter would carry it northeastward to the North Kistler quarry.

The slate on the dump is broadly ribboned. Bedding and cleavage intersect at a very low angle, so that even in the closely "ribboned" strata long cleavage surfaces of clear stock are obtainable. The beds are cut by numerous small joints filled with aragonite and quartz; the case cited elsewhere (Figure 16, page 39) is from this quarry.

Nothing is known of the history of operations here.

15. *South Kistler Quarry.* This is located due east of the Kistler farm house, and south of the North Kistler quarry, on the hillside east of the stream. It is 20 by 40 feet in plan and shows 10 feet of slate in the walls. The beds strike $N.68^{\circ}E.$ and dip $65^{\circ}N.$ at the surface, but steepen downward. Cleavage strikes $N.80^{\circ}E.$ and dips $84^{\circ}S.$ The structure is thus the north limb of an anticline, probably the one seen

in the Daniels quarry (Quarry No. 9). The grain trends N.30°W., dips 85°W.

One big bed, estimated to be 7 feet thick, is exposed. The material on the dump is of fair quality, not closely ribboned and showing no aragonitic veinlets.

The history of this opening is not known. Like Quarry 14, it is on the farm of Howard D. Kistler. Both quarries have long been idle.

16. Henry Quarry. This large opening is about three-quarters of a mile north of Wanamaker, in the valley of a tributary of Ontelaunee Creek. It is 330 by 135 feet in plan, has 40 feet of slate above water level, and is probably at least 100 feet in total depth. The southwest wall shows a beautiful syncline, tipped toward the north. The axial plane, like the cleavage, strikes N.60°E. and dips 75°S. The beds strike N.45°E. and dip 60°N. on the south limb of the syncline, in the east corner, thus indicating a strong westerly pitch of the fold. This syncline is inferred to be that of the Kalbach quarry. Grain trends N.40°W. and is vertical.

One big bed at the southeast edge of the opening is about 15 feet in actual thickness. The sequence above it was measured in detail but could not be correlated with any of the strata of the Slatington region for which data are available. The big bed may represent one of those in the Peach Bottom, Williamstown, Trout Creek, or Keystone "runs." Of these, the areal position and proximity to the sandy middle Martinsburg contact favor correlation with the Upper Williamstown big bed, though there is at least some resemblance between the succession of "ribbons" above the big bed in this quarry and that above the Manhattan big bed.

The slate on the dump has excellent cleavage, lacks undesirable jointing, and still has a good ring, despite several years exposure.

Nothing is known of the history of operations. The quarry has evidently been abandoned for a long time.

17. South Hermany Quarry. About three-quarters of a mile east and slightly northward from the Henry quarry, west of the road to Blue Mountain, and on the land of Thomas G. Hermany are the two Hermany quarries. The northern of these is 75 feet square, and shows 15 feet of slate above the water with which it is filled. This face of slate is not accessible, but from a distance it seems to show bedding striking northeast and dipping 75°S., whereas the cleavage dips about 30°S.; these observations must be essentially correct, for similar relations are observed in the road near the quarry, where the strike of bedding is N.60°E. and the dip 88°S. The structure is thus the overturned north limb of an anticline.—probably the same axis as that inferred to lie south of the South Kistler quarry.

This quarry was last worked in 1884. It is said that at the south end much "spar" (probably aragonite, calcite, and quartz filling in joints) was found. Drilling in the bottom to a depth of 525 feet revealed no change in the direction of the dip.

18. North Hermany Quarry. This is about 200 feet north of Quarry 17. It is 75 by 40 feet in areal dimensions, and probably

shallow, but now filled with water. The dump shows typical soft slate of good quality.

19. This old cut, 30 feet square, is situated on the south bank of the same tributary as that on which Quarries 17 and 18 are located, about three-quarters of a mile north of the church at Jacksonville. Near the north edge it shows one big bed, estimated to be 10 feet thick, which strikes $N.70^{\circ}E.$ and dips $61^{\circ}S.$, whereas the cleavage strikes $N.73^{\circ}E.$ and dips $28^{\circ}S.$ The structure is thus the north limb of a northward-tilted anticline, but is so far north of most of the other quarries as to make it improbable that it is continuous with any fold described in quarries to the west.

The slate seen on the dump is of good quality, with excellent cleavage, little jointing, and no close ribboning.

This quarry has evidently long been abandoned.

20. *South Shenton Quarry.* Half a mile north of Lynnport, on one of the headwaters of Ontelaunee Creek, are four openings, commonly called collectively the Shenton quarries. The southmost is on the east bank of the stream, whereas the other three (see Quarry 21) are in the stream bottom or on the west bank. This south quarry has, in this report, been described under a separate number. It is about 80 feet square, and shows a little slate above water level at the northeast side. The beds cannot be distinguished but the cleavage strikes $N.60^{\circ}E.$, and dips $62^{\circ}S.$

The quarry has long been abandoned.

21. *Shenton Quarries.* These are the three northern openings of the quarries mentioned under Quarry 20, above. The southmost (Quarry *a*) is a cut in the hillside, showing 25 feet of bed rock. A big bed estimated to be 12 feet thick, with ribboned slate above, strikes $N.62^{\circ}E.$ and dips $15^{\circ}N.$; cleavage strikes $N.62^{\circ}E.$ and dips $42^{\circ}S.$ The opening is thus just south of an antilinal crest, the fold being tipped over northward. Grain trends $N.28^{\circ}W.$

Some 100 feet north of Quarry *a* is a slate pit 50 by 35 feet in plan, showing 35 feet of bed rock in the southwest side. Here the strata strike $N.65^{\circ}E.$ and dip $80^{\circ}S.$, steepening downward and finally dipping northward. The cleavage strikes $N.60^{\circ}E.$ and dips $45^{\circ}S.$ One big bed with a thickness estimated at 10 feet, appears in the middle of the quarry wall, and the relations between it and the beds to the south suggest a bedding slip fault at its base. Structurally this quarry clearly lies north of the antilinal axis inferred from the structural relations between cleavage and bedding in Quarry *a*.

From Quarry *b* 150 feet north, is a larger opening (Quarry *c*) 80 by 60 feet in area and probably 50 feet deep. The beds here strike $N.65^{\circ}E.$ and dip $66^{\circ}S.$; cleavage strikes $N.78^{\circ}E.$ and dips $40^{\circ}S.$; the structure is thus like that in Quarry *b*.

Two big beds are seen here in the southwest wall. The upper is 18 feet thick and the lower 19 feet, with $17\frac{1}{2}$ feet of banded slate between. One of these is said to have been excellent material for blackboards. A definite correlation with any of the "runs" seen at Slatington could not be established but it is at least probable that these strata belong in that part of the standard section that lies below the Blue Mountain "run."

The anticlinal axis south of Quarry *b* is probably that inferred to lie south of the South Hermany quarry, because the two openings are essentially on the same strike line.

Several old buildings stand on the dump but the quarries are now idle. They were used for a time to supply the mill at the Hess or Ontelaunee quarry in Lynnport.

22. *Hess (Ontelaunee) Quarry.* A large quarry is situated about a quarter of a mile east of Lynnport, and 700 feet north of the Lynnport-Slatington highway. It is 290 by 200 feet in plan, with several irregular reentrants on the sides. Though filled with water, it shows 50 feet of slate in the walls and must have attained great depth, to judge by the size of the dump.

The most conspicuous feature is the almost parallel attitude of beds and cleavage. In the north corner, for example, the beds strike N.80° E., dip 61° S., whereas the cleavage, striking parallel, dips 57° S. In the south corner the beds are horizontal, whereas the cleavage dips gently north, or dips south at a lower angle than the bedding. The cleavage is conspicuously curved (see Plate 61, A) notably on the southwest side, and here are numerous joints, dipping vertically, striking N.50-70° E., and filled in many cases with calcite. This flat position of the cleavage, coupled with its curvature, and with the shattering by jointing, all seem to suggest the Eckville fault hypothesized to lie south of the opening. If the fault was a thrust, moving on a gently dipping plane, the cleavage, which elsewhere is generally nearly vertical, might readily be tilted to its present horizontal position.

The relation between cleavage and bedding show that the structure here is the north limb of a greatly overturned, well-nigh recumbent antiform, another feature suggestive of post-cleavage faulting, since the other folds seen in this region usually exhibit axial planes that are tilted only slightly from the vertical. The grain trends N.15° W., and dips 85° E.

This quarry was opened previous to 1880, for it is mentioned by Sanders¹. It has passed through several hands, but is now controlled by the Shenton Slate Company, which also operates the Locke quarry at Slatedale. The Hess quarry was not actively productive in 1927, and is only worked sporadically. The equipment includes a large, well designed mill for making structural slate, much of the raw material being obtained from the Locke quarry. Many turned structural products, such as sinks, are also produced, and one unusual feature is the making of registers or gratings for hot-air heating on a drilling machine especially designed. Much marbleized slate was also once manufactured here.

23. *Kuntz Quarry.* This is 300 feet north of the highway from Lynnport to Slatington, about one mile east of the former town. As the quarry is on a height of land, the dump is a readily visible landmark. The opening is 70 by 155 feet in area and full of water, only 3 feet of slate showing above water level. The cleavage strikes N.55° E. and dips 62° S., and the bedding is not recognizable in the small outcrops of bedrock above water.

The blocks on the dump show irregular, frequently curved cleavage.

¹ Sanders, R. H., op. cit., p. 125, 1883.

A few show false cleavage, and many have joints, spaced as closely as at 2 or 3 inch intervals. Many blocks are conspicuously sandy. On cleavage surfaces depressions are seen to contain small, glistening areas, up to $\frac{1}{2}$ inch in diameter, of a substance with pitchy luster, like gilsonite, but far less combustible. Very little ribboned slate is seen, the bedding and cleavage intersecting at very low angles. From analogy with the Hess quarry, it is thought that the bedding here is probably overturned northward and thus on the north limb of an antiline.

No equipment remains, and the quarry has been abandoned, it is said, since about 1917. It was owned and first operated by Erwin Probst and later by the Slatington Slate Company.

24. Bauer Quarry. Approximately $1\frac{1}{2}$ miles west of Mosserville and an equal distance northeast of Lynport is an abandoned slate quarry on the hillside overlooking the headwaters of a tributary to Ontelaunee Creek. The opening is 90 by 200 feet in size and about 40 feet deep to the waste and water which fill the bottom.

The structure here is the north limb, partly overturned, of an anticline. At the south edge the beds strike $N.54^{\circ}E.$ and dip $70^{\circ}S.$, but the dip steepens farther north and at the northwest edge it is $75^{\circ}N.$ The cleavage strikes $N.70^{\circ}E.$ and dips $46^{\circ}S.$; the westward convergence in the strikes of cleavage and bedding suggests a westward pitch. Grain trends $N.40^{\circ}W.$ and is vertical.

Four big beds are seen here. One, approximately 15 feet thick, reaches the surface 20 feet north of the southeast edge of the quarry. Stratigraphically about 100 feet higher are two big beds, the lower 10, the upper (and northern) 7 feet thick, separated by about 10 feet of "ribboned" slate. Still higher by 33 feet is a pair of big beds, the lower $11\frac{1}{2}$, the upper 18 feet in actual thickness, separated by 22 feet of ribboned slate. In detail this sequence does not agree perfectly with that of any of the "runs" at Slatington and no correlation could be established. The nearest approach, on the basis of the thickness of big beds and of intervening strata is furnished by the sequence from the Upper Columbia big bed down to the Second (Middle) Loeke big bed (see page 187). Most of the work was done in the lowest of the big beds mentioned.

The slate on the dump splits well and false cleavage is lacking. The several thick beds separated by so little waste should be a circumstance favoring operations.

A large mill building standing north of the opening still contains machinery. The quarry was last worked about 1915. Nothing else is known as to its history.

25. Laurel Hill Quarry. This is situated half a mile southwest of the last (No. 24), in the stream valley. It is a large opening about 180 feet square, showing only water to the level of the ground. In the stream bed nearby, however, slate outcrops, the beds striking $N.60^{\circ}E.$ and dipping $16^{\circ}S.$, whereas the cleavage strikes $N.68^{\circ}E.$ and dips $70^{\circ}S.$; structurally, therefore, the quarry is south of the anticlinal crest mentioned as occurring south of Quarry 24.

On the dump typical soft slate is seen; it has excellent cleavage. Structural slate, including registers, was produced here. The quarry

was in operation as early as 1880; mention is made by Sanders of a 26-foot bed which was worked.

26. *Mosserville Quarries.* These two openings lie respectively a quarter and four-tenths of a mile south of the little settlement of Mosserville, west of the road to New Tripoli. The northern is a tunnel with water now standing in the bottom. The beds at the portal strike N.65°E. and dip 12°S., while the cleavage strikes N.82°E. and dips 42°S. The beds are clearly steepening northward. Structurally an anticlinal crest evidently lies to the north.

No conspicuous big beds are seen. The products were largely structural material, including sinks and mantels. The last operations were carried on about 1912.

The southern opening is a quarry, originally consisting of two openings separately worked and united in the progress of operations. It approximates 300 by 100 feet in area and has a depth of 40 feet to water level, though probably 20 feet deeper. Two conspicuous big beds were worked. The slate is not closely ribboned but shows numerous shear zones and much curved cleavage, the cleavage deformation frequently being in sharp crinkles or zigzags; false cleavage striking N. 60°E. is prominent also.

The outstanding structural feature, however, is the fact of pitch. Wherever observed the cleavage strikes N.65-75°E. and dips 45-50°S. The bedding, however, is highly variable. Thus, at the south edge of the quarry at water level, the strike is N.60°E. and the dip vertical, evidently on the south, overturned limb of a syncline. At the northwest corner, however, the strike is N.10°E. and the dip 75°NW. This, coupled with the observations at the portal of the tunnel, mentioned above, clearly shows that the general structure is a westward pitching syncline. It accounts readily for the occurrence of sandy beds (presumably in the middle Martinsburg) to the northeast, between Mosserville and Jordan Valley. The arm-like area of slate between Mosserville and New Tripoli is a syncline folded between sandy beds of the middle member of the Martinsburg formation. The eastward end of this "arm" in the pitching trough described is somewhat uncertain and there is a suggestion in the topography that it may extend all the way east to Germansville, following the valley of a headwater of Jordan Creek.

The Mosserville quarry has long been idle; the last operations were about 1900.

27. *Sieger and Kraus Quarry.* This is on the east side of the road, opposite the Mosserville quarry just described. It is a hole 150 feet square, now filled with water but said once to have reached a depth of 90 feet. The material on the dump shows much "curl" or false cleavage. Work here was last carried on in 1895.

28. An old quarry, long deserted, lies far distant from any others in the Lynnport group, about a mile north of Mosserville. It is in part a cut into the hillside in the east bank of that headwater of Ontonagon Creek which flows south toward Mosserville. The bedding and cleavage strike parallel, about N.65°E., but the dip of the beds is south and steeper than that of the cleavage; overturning is inferred.

No conspicuous big beds are seen. The slate on the small dump appears to have good cleavage and is very little discolored, though evidently exposed to the weather for many years.

The chief significance of this opening is in the fact that it demonstrates the presence of a continuous band of workable "soft" slate north of the sandstone belt that marks the middle Martinsburg; structurally, too, the dip relations of cleavage and bedding at this quarry indicate that the "soft" slate, on the overturned, north limb of an anticline, lies stratigraphically above the sandy beds of the middle member, rather than below them as maintained by Stose.

LOWHILL GROUP.

The quarries of this group are widely scattered in Heidelberg and Lowhill Townships, in western Lehigh County, a little east of the Berks County line. They are grouped together only in the interest of simplified treatment. Three are in the "hard" slate of the lower member of the Martinsburg; the fourth and northern is in shaly strata interbedded with the sandstones of the middle member of the Martinsburg. In all, the production is from closely banded slate.

All of these quarries have long been abandoned with no prospects of early resumption. None is readily accessible to rail transportation.

1. *Flint Hill Quarry.* This pit, long idle, was about a mile west of Pleasant Corners, on the short road to New Tripoli. Now the hole has been filled with rubble, and only a small dump remains as evidence of the former existence of the quarry. The slates seen split well. Bedding and cleavage are nearly parallel, the divergence amounting to no more than 5° . Thin calcareous layers control the split to a certain extent, and cleavage flakes are apt to be thicker at one end, wedging out in the direction of the convergence of cleavage and bedding. In the road cut just south of the dump, thin-bedded sandstone, typical of the middle Martinsburg, is seen. The structure at the probable quarry site is uncertain, but may be assumed to be characterized by closely folded bedding.

This slate is interpreted as being in a lens within the middle, sandy member of the Martinsburg formation. Similar occurrences of workable slate layers have been described in the northeastern part of the Lehigh-Northampton slate belt, near Johnsonville (see page 256).

2. *Bachman Quarry.* About two-thirds of a mile north of Weidaville, in the valley of a tributary to Lyon Creek, is an old slate quarry 35 by 60 feet in ground plan. It cannot have been a deep opening, to judge by the size of the dump. Some thirty feet of typical "hard" slate are seen in the west side, but the structure is not clear. The slate blocks on the dump are largely composed of sandy beds, closely "ribbed," and the cleavage is nearly parallel to the bedding and very irregular.

This quarry was opened in 1887; it was never a very successful operation, and is now idle.

3. *West Claussville Quarry.* This is situated a quarter of a mile south of Claussville, west of a road. It is not more than 20 feet deep below water level. No slate remains on the dump, but a little that

shows above the water is typical "ribboned," "hard" slate. The quarry has been abandoned since 1900 at least.

4. *East Claussville Quarry.* In general location this opening resembles Quarry 3, but is east of the road. It exhibits the same geological relations as the West Claussville Quarry, which it also resembles in size and in history.

TREICHLERS GROUP

Near the northeast edge of the Slatington quadrangle, in Whitehall and North Whitehall Townships, Lehigh County, and in Allen and Lehigh Townships, Northampton County, are twelve isolated slate quarries. All are in the lowest member of the Martinsburg formation except the Rockdale quarry (No. 2). Some lie close to Lehigh River and therefore would have ready access to the Lehigh Valley and Central of New Jersey railroads, but a few are so far away from these means of transport that their operation would probably necessitate trucking. All are now idle.

All of the quarries of this group are in closely "ribboned" slate, but the angle of intersection of bedding and cleavage is generally so low that very little banded slate has been produced. In many places certain slate beds, especially those that are slightly coarser in texture, break free, and thus a piece is obtained one large surface of which is a bedding plane, and the other represents the cleavage (see Figure 19). Such pieces are satisfactory when small slates are desired, but when large ones are needed the thicker end becomes undesirably heavy.

1. This old opening is 0.8 mile west of Rockdale on the south bank of Rockdale Creek. It is only 35 feet square and, as usual, filled with water, some 10 feet of slate showing in the eastern corner. The cleavage here strikes N.73°E. and dips 26°S., whereas the beds strike parallel but dip 31°S. This gentle angle of intersection, in view of the tendency to break along thin, calcareous and slightly more quartzose beds, makes it possible to produce tapering roofing slate pieces such as were mentioned in the preceding paragraph.

Some finished roofing slates, still possessing a good ring when struck and exhibiting very little discoloration, are to be seen on the dump. The quarry has however long been abandoned. It is possible that this or Quarry 2 is the oldest opening in the entire district.

2. *Rockdale Quarry.* About 1000 feet southwest of the Lehigh Valley Railroad station called Rockdale, and up the valley of Rockdale Creek, is a small cut 20 feet square and 10 feet deep. It shows closely bedded slate like the "hard," "ribboned" slate of the lower Martinsburg. The individual beds are rarely more than one inch thick. Some are sandy and along these the slate tends to split. The angle between bedding and cleavage planes is small enough, however, to permit the making of some slate in the same manner as was described for Quarry 1. Nevertheless, the prospect is not promising.

This pit has been long abandoned.

3. *Big Rock Quarry.* East of Lehigh River, about half a mile east of Treichlers Station on the Central Railroad of New Jersey, is an old slate quarry (See Plate 61, B). It is 100 by 120 feet in size and



A. Northwest side of Hess quarry at Lynnport, to show curvature of cleavage.



B. Big Rock quarry at Treichlers: beds dip 30° to observer's right (south); cleavage dips more gently.

shows 50 feet of slate in its north wall. Being very close to the railroad tracks, it is especially well situated for shipping; a drainage tunnel once led under the tracks from the quarry to the river.

The slate here is typical, closely banded "hard" slate, but cleavage and bedding intersect at small angles, their strikes being parallel; thus, the dip of the cleavage is 18° S., whereas that of the bedding is 30° S. These relations are remarkably uniform in the opening, especially when the close folding southward along the railroad track is noted.

Near the surface the cleavage is curved, but at the bottom it is regular and excellently plane. Individual beds are up to 8 inches in thickness, but as the slate splits well on the cleavage and is not affected by parting along the stratification the close spacing of the bedding planes is not a seriously deleterious feature. There is nevertheless a tendency for the slate upon prolonged weathering to break along certain beds. Many of the slates made here, however, because of the small angle between bedding and cleavage, give the appearance of clear stock.

This quarry was opened about 1885. Though operations were not continuous, there has been sporadic quarrying for roofing slate for local purposes even in recent years. It is said that school slates were once made here from the "unribbed" cleavage pieces.

4. *Frantz Quarries.* About $1\frac{1}{2}$ miles southwest of Laurys Station, in the valley of a small tributary of Fells Creek is a larger opening, 140 by 90 feet in ground plan and showing 30 feet of slate above water level. It is now mostly filled with waste. Some 100 feet northeast is a small hole, 30 feet square. In the latter the cleavage strikes due east and dips 30° S.

Both quarries show thin-bedded, typical "hard" slate with sandy calcareous "ribbons". The slate chips seen split as do the products of most of the quarries of this group, with one surface parallel to the bedding, giving wedge-shaped pieces.

These two openings have long been abandoned.

5. *Roth Quarry.* This old opening is about a mile due east of Scheidy, in the valley of a tributary of Spring Creek. It is 165 feet square, but of irregular shape. Its total depth must be about 100 feet, but now a thickness of only 40 feet of slate shows above water level.

The bedding strikes about $N.85^{\circ}E.$ and dips gently south. Cleavage has a strike parallel to the bedding, but dips somewhat more steeply; the cleavage planes, however, are slightly "wavy". Conspicuous joints were noted dipping vertically and striking approximately parallel to the cleavage.

The slate made here shows very little "ribboning", because of the gentle angle at which the cleavage intersects the beds. In addition to roofing slate of good grade, some structural slate was produced here.

The quarry was operated by Slatington capital. It was shut down in 1876, yet slate chips on the dump show no appreciable discoloration.

6. *North Cementon Quarry.* This is the northwesterly of two old slate quarries about $\frac{3}{4}$ mile west of Cementon. It is completely overgrown and shows only a little weathered bed rock in which structural features are indistinguishable.

7. *South Cementon Quarry.* This is about 200 feet south of Quarry 6. It is 30 feet square and probably has a depth of 25 feet. The cleavage

strikes N.80°E. and dips 25°N., a surprising feature, possibly related to fault drag, as the contact between the Martinsburg and the underlying limestones is locally along faults in this general region. Much "ribbed" slate is produced, for the bedding meets the cleavage at high angles. The quarry has clearly long been abandoned.

8. *Reservoir Quarry.* This old slate quarry, overlooking the town of Cementon to the southeast, has now been converted into a reservoir. The slate blocks found there evidently represent quarry waste; they show thinly banded slate, in which bedding and cleavage meet at low angles. Curved cleavage is seen in some pieces. Nothing is known of the history of operations here.

9. About 1½ miles north of Siegfried (Northampton) Station, along the Central Railroad of New Jersey, is an old slate quarry, long abandoned. It is 40 feet square and shows 5 feet or so of slate, not accessible, above the water with which it is filled. The cleavage planes are approximately horizontal, but are commonly somewhat curved. The hole has clearly long been abandoned.

10. In the bottom of a small stream that enters Lehigh River from the east, approximately 1½ miles north of the railroad station at Siegfried (Northampton), is an old opening, now hidden in the woods, about 120 feet square and showing 30 feet of bed rock in the northwest side. The slate is closely "ribbed", typical "hard" slate. A few beds weather unevenly; otherwise there are no unusual qualities. This quarry, too, has long been deserted.

11. About 600 feet east of Quarry 9, on the slope of the hill overlooking Lehigh River, is a small hole, 40 by 60 feet in surface area and possibly 40 feet deep, but now filled with water. Here is typical "ribbed" "hard" slate, loose chips of which show bedding and cleavage meeting at low angles.

Several cuts show nearby, but no quarrying has been done here in recent years.

WALBERTS GROUP.

The southeastern edge of the Martinsburg formation in Lehigh County shows a series of arms or tongues projecting eastward into an area underlain by earlier limestones; locally these tongue-like forms become completely cut off from the main area of the Martinsburg formation, constituting outliers. The structural reasons for the appearance of such more or less isolated areas of the Martinsburg within the Ordovician and Cambrian limestones have not been worked out; Dale¹ and Miller² have attributed many of the irregularities to fault patterns of various kinds, and some are unquestionably the result of infolding.

One of these, resulting probably from such infolding, is Huckleberry Ridge, in the east central part of the Slatington quadrangle. The westward-pitching syncline, to the presence of which this mass of Martinsburg slates can best be attributed, has preserved some hard slate in a single quarry, though several clay pits have been worked in the as-

¹ Dale, T. N., Unpublished notes; made available through the courtesy of the Director, U. S. Geological Survey.

² Miller, B. L., oral communication.

sociated shales, as a quarter of a mile north of Wenmersville and a mile north of Walberts.

1. *Snydersville Quarry.* About 0.7 mile east of Snydersville, just north of the road from that hamlet east toward Eckert, is an old slate quarry on the Garnet property. It is 40 by 100 feet in area and reputed to have reached a depth of 90 feet, but is now full of water so that only 20 feet of slate shows in the walls. The bedding and cleavage strike approximately parallel, $N.70^{\circ}E.$; the beds dip $50^{\circ}S.$ and the cleavage $20^{\circ}S.$ Jointing is conspicuous, striking $N.80^{\circ}E.$ and dipping vertically. The grain trends $N.35^{\circ}W.$ and is vertical.

The slate blocks on the dump cleave well, but show local wrinkling, and some are affected by quartz-filled joints. On the whole, the "ribbons" are not planes of parting, so that typical hard slate of uniform thickness could well be made.

This quarry has not been worked for 50 years or so. It is mentioned by Sanders as being idle as early as 1880¹.

GREENAWALD GROUP.

The quarries of the Greenawald group are located near the hamlet of that name, in northeastern Berks County. They have never yielded slate in slabs suitable for roofing, flagging, or structural uses, but their product has been crushed and granulated or powdered, to serve as slate chips on tar roofing or as filler with pigmenting qualities. Since they enter into competition with the "soft" and "hard" slates of the district, however, and furnish an economically important slate-like product, they are described here. As a reminder that these openings do not yield roofing slate or slate for structural purposes, their location has been indicated on the maps by means of crossed picks, instead of the quarry symbols generally employed for those openings yielding roofing or structural slate.

The red and green slates occur as beds interstratified with the coarse, sandy layers of the middle Martinsburg. Like the latter, they show much folding, and, being more plastic than the sandy beds, they have been folded even more intensely. The details of these folds are indicated in the small scale map (Plate 25) and are also discussed in the descriptions of the individual quarries. Since the beds are not homogeneous through great thicknesses, they have not developed the uniform cleavage seen in the gray slates of the "hard" or "soft" belt. The fracture is only partly along cleavage planes; it is in many cases parallel to jointing and most commonly determined by bedding.

In appearance the workable part of these rocks consists of thin, slabby beds, generally from 1 to 3 inches thick. These are shaly to slaty in structure. They are all fine-grained, that with coarsest texture approximating a fine sandstone. In color they exhibit various shades of purple, green, and ocher-yellow. So great is the variation, that a definite color designation is impossible. Typical reds and reddish browns are 9"m and 5"i of the Ridgway color standards.² The greens vary from bright grass green to olive gray. There are frequent occurrences in the red slates of noteworthy patches up to a foot in diameter having light green color and evidently representing areas of alteration.

¹ Sanders, R. H., op. cit., p. 123, 1883.

² Ridgway, Robert, Color standards and color nomenclature, Washington, D. C., 1912.



A. View into large red and green shale quarry at Greenawald; the irregular light-colored areas represent zones of reduction and leaching, now light green in color.



B. Small drag folds and thrust faults in sandy layers near red shales, in railroad cut half a mile south of Albany Station.

Streaks of this type also follow joint planes (see Plate 62, A). A brief discussion of these color differences in relation to mineral content is given below.

Microscopically these rocks may be best classed as clay slates. They show slightly less metamorphism than the true slates of the "soft" and "hard" belts (see pages 182 to 184). Mineralogically they contain much kaolin (or other related minerals of the group of hydrous aluminum silicates) in very fine masses. Considerable quartz in sub-angular to rounded grains is seen. Some carbonate is also present, especially in the more sandy layers; it weathers to limonite and hematite. Finally, there are large amounts of sericite, which contributes brilliant aggregate extinction in sections at right angles to the cleavage. Chlorite is present, but is not conspicuous in amount and the crystalloblasts or metacrysts of chlorite noted in the soft slates are lacking. Graphite is conspicuously absent. Mineralogically the slates resemble the Gray beds of Bangor, Pen Argyl, and Slatington, but bear more "kaolin."

In detail, the quartz is partly in larger grains up to .03 mm. in diameter; these are rounded and show none of the secondary growth remarked in the "soft" or "hard" slates. Some beds are almost fine arkosic sandstones in their preponderance of quartz grains, with occasional feldspar individuals, somewhat rounded. The quartz also occurs in fine aggregates of smaller grains, of which the individuals are generally angular to subangular; these masses probably represent silty matter enmeshed in colloidal clay when deposited.

Sericite varies in character. The main mass of the rock consists of this mineral. In thin sections parallel to cleavage the individuals are cut in basal sections and are dark, but oriented sections at right angles to cleavage exhibit fair parallelism in mineral elongation, not as perfect by any means as that in the "soft" and "hard" slates, but still displaying good aggregate extinction.

The most striking mineralogic characteristic of these colored slates is the hematite which suffuses the mass of the red slates and is absent from the green. It is evident that the former are the oxidized equivalents of the latter. It is also clear that most of this oxidation antedated deposition, for it is delimited by bedding planes; in the absence of differences in porosity, the parallelism between color and bedding suggests the syngenetic origin of such differences.

A second type of color differences, however, can only be explained on the ground of reduction, a process the chemistry of which in this instance is not well understood. Along joint planes the red, especially of the bright red facies, is altered to a pale green, similar to that of the unaltered greenish beds. The same type of change forms spherical areas, especially conspicuous on the cleavage planes, generally with a foreign particle in the center. These particles, so far as examined petrographically, are chlorite and quartz; no pyrite or other agent that might be expected to produce reduction of the surrounding matter was found.

The various quarries of this group have been operated discontinuously for twenty years or more. In 1927 one was in intermittent operation at Greenawald and another at Lenhartsville. With them is generally associated a plant for granulating or powdering the slate quarried.

In addition to the larger pits described below, the red somewhat sandy shales have been worked in several places, notably on Stony Run,

about a mile northeast of Spitzenberg. They find favor as road metal and for this purpose lesser pits are commonly developed in the red beds in the general neighborhood of Kempton, Albany, and Greenawald. As of possible industrial interest, the outcrops of these red and green shales have been plotted on the small scale map with as much accuracy as the reconnaissance nature of these studies permitted.

1. *Albany Quarry.* This is half a mile south of Albany, on the west bank of Maiden Creek. The opening is 300 feet wide along the strike and 100 feet down the dip, with a maximum depth of 80 feet. For a thickness of 200 feet the rocks are thin-bedded, pencil-shattering, olive green clay-slates and shales, and brick red to purple shales, with occasional bleached areas for 100 feet. The beds are greatly compressed, but generally strike $N.75^{\circ}W.$ and dip $70^{\circ}S.$ Similar details of structure are shown in the railroad cut a quarter of a mile northeast of the quarry (see Plate 62, B).

This quarry was made by the Atlas Mineral Products Company, having first been opened in 1915. A mill for crushing the slates was erected in 1918. When this structure burned down in 1924, the quarry was abandoned.

2. *Ruth Quarry.* This small pit, 60 feet square and about 50 feet deep, is the northwestmost of those at Greenawald. It is near the Greenawald Station on the Reading railroad, and some 300 feet east of the main road on the east side of Maiden Creek. The beds strike $N.70^{\circ}E.$ and dip $60^{\circ}S.$, but there is much close folding. The slates are red and green, like those described at the Wilbur quarry (No. 3).

This operation is a small one, the pit being worked only occasionally and the product being hauled to the railroad by team.

3. *Wilbur Quarry.* This large opening is 500 feet southeast of the Greenawald Station (see Plate 62, A). It measures 400 by 80 feet in area and has a maximum depth of 60 feet. The beds generally strike $N.60^{\circ}E.$ and dip $65^{\circ}S.$ Cleavage is not well marked, the chief fracture planes being along the bedding. The dominant color is bright brick red, bleached here and there, partly along joints, partly in circular areas like those mentioned above. The red, light green, and dark green colors are all distinctly banded with the bedding, the poorly developed, pencil-fracturing cleavage planes crossing the bedding indiscriminately and without relation to the present color. Brown beds are also seen, especially at the entrance of the cut; these are sandy and calcareous.

The general structure is monoclinal, with northward overturning. Close folding predominates, and one small, tight anticline shows in the north wall but in crossing the pit is pinched to the appearance of a monoclinal structure.

The product of this quarry is delivered by a spur line to the railroad and shipped away for further treatment. In crushed form it is used for covering roofing paper, and when finely ground as filler for coarse cloth and roofing paper. The producing company is the Wilbur Job Company of Rhode Island.

A short distance southeast of the foot of the incline leading from the quarry last described is a small opening, not separately mapped. It is 100 feet square and now deserted and filled with water. Yellow, ocherous shales were worked here for linoleum filler.

4. *Focht Quarry.* This large pit is about 450 feet northeast of the Wilbur Quarry. It consists of a series of partly connected openings aggregating about 500 feet in length along the strike and 100 feet in width, with a maximum depth of about 60 feet. The structure closely resembles that of the Wilbur Quarry, the cleavage dipping south more gently than the beds. There is also some faulting. The south edge shows much green slate, but most of the opening is in red, slightly gritty beds.

This property is owned and was once operated by J. S. Focht of Greenawald. Operations were begun in 1890, but were later shifted to the Wilbur quarry (No. 3).

5. *Lenhartsville Quarry.* This is situated on the east side of Maiden Creek, half a mile east of the town of Lenhartsville. It has the form of a cut opened 50 feet along the dip and 120 feet along the strike of the beds. The immediate structure is a small, tight syncline, with axis striking about east and west, and axial plane dipping, like the cleavage, approximately 45° S. The south limb is overturned and somewhat thicker than the north. The trough in the fold is shown in the narrow cut by which the quarry is entered. Near the northeast edge an indistinct fault plane, striking about $N.20^{\circ}W.$ and dipping vertically, cuts across the quarry face; it seems to have moved the north side southwest and up, to judge by the striae on the fault surface and the repetition of beds.

The strata opened are purple, red, and brown, as well as green. The brown layers are sandy, calcareous, massive, and show cross-bedding; being relatively brittle, they are broken and worn smooth by movement, so as to resemble large boulders. These are best seen in the entrance to the pit. The changes of color from red to green and vice versa are chiefly confined to bedding differences, but locally there are changes from one to the other in the same bed. The marked "bleaching" of the red beds noticed at the Wilbur quarry is not to be seen here, however.

This quarry was worked for colored slate in 1890 by J. S. Focht, but operations probably date even farther back, for it is said that attempts were made once to use the red rock for iron ore and an old furnace still stands on the ground. Later yet quarrying was abandoned because of large amount of waste. In 1918, however, work was resumed here and has continued with minor interruptions, to the present time. In the year mentioned a mill was installed, earlier work having yielded only the "raw", coarsely crushed material which was sent to Philadelphia for finishing.

The present operators (Greenwich Manufacturing Company) have installed a train for hauling from quarry to mill. In the latter the flow sheet includes drying in a low temperature kiln, transferring by bucket conveyor to a ball mill, thence by worm conveyor to a tube mill, and then sizing by means of a Gates type separator, the oversize being returned to the ball mill. The crushed product is used as a filler and pigment.

HISTORY OF THE LEHIGH-NORTHAMPTON DISTRICT

In a small way at least, slate has been produced in Lehigh and Northampton Counties for a century. The first operation recorded was in the hard belt by a company from Baltimore which in 1828 began

quarrying west of Laurys Station in Whitehall township, probably at the Rockdale quarry of this report.

In 1831 slate was discovered on Benninger's farm, east of Slatington, and probably near the site of the present Genuine Washington quarries, but extensive quarrying on a commercial scale is not known to have been done here before 1844. In that year, according to tradition, the land mentioned was leased by William Roberts and Nelson Labar, who became interested in quarrying from seeing slate outcrops while on a walking trip from Easton to Mauch Chunk. In 1845 the Welshtown tunnel, too, was opened and the expansion consequent on this and other quarry operations led to the laying out in 1851 of the town of Slatington by the Lehigh Slate Company, then the chief producer¹.

About 1850 slate was discovered at Bangor by Robert M. Jones, the founder of Bangor, whose statue is seen at the Bangor High School, on the hill east of that city, where the masts of the Old Bangor quarry now stand. At this time, too, the Chapman quarries in the hard belt were developed, the charter of the present company being dated 1864.

Thus by 1855 the slate quarry industry, stimulated by Welshmen who were instrumental in persuading experienced slaters from Wales to emigrate to this country, was already thriving and growing by leaps and bounds. Indeed in 1850 or thereabouts, Rogers, then State Geologist of Pennsylvania, and his associates found five quarries in operation at Slatington and two more near the Delaware Water Gap², one of the latter apparently being the Old Jersey quarry, east of Delaware River. Rogers even writes of one quarry as having been opened in 1812, but this statement is probably incorrect.

The first school slate factory in the district was started by James and Roberts in 1847 on Factory Street in Slatington, which thus became the center of school slate production in the United States. Five years later blackboard making also began, certainly at Slatington and probably at Bangor as well. Sales of roofing slate, however, formed the backbone of the industry.

By 1880, when Sanders studied the district for the Pennsylvania Geological Survey, slate quarrying was in full swing at all the present centers of production. Indeed in many cases Sanders reports large quarries that had been worked out and abandoned.

In its subsequent growth the district has suffered the depressions and revivals experienced by the slate industry of the country as a whole. The introduction of channelling represented a marked advance and served as a stimulus; in 1863 it was first practiced in Vermont³ and probably reached Pennsylvania a decade later. The appearance, however, of asbestos, paper and tar roofing materials shortly before the peak production in 1903, heralded a general decline in demand for roofing slate. At the same time, school slate consumption suffered greatly through displacement by cheap paper and at the hands of the sanitary experts of our public schools. This was accompanied by an intense price competition among the slate men themselves.

There ensued, then, a period of marked distress in the industry. Labor costs had risen. Some of the old markets for slate products were

¹ This and other related data are obtained from *History of Lehigh County*, vol. I, 1914.

² Rogers, H. D., *Geology of Pennsylvania*, vol. 1, pp. 258, 249, 1858.

³ Merrill, G. P., *Stones for building and decoration*, John Wiley and Sons, New York 1910, p. 404.

on the wane with no possibility of any recuperation in the future; others were being invaded by substitute materials. Freight rates were prohibitive for distance shipments. Added to this, cost accounting was not recognized as furnishing a basis for proper sales prices; expenses were incurred in quarry operations, while prices were being cut in a manner wholly unjustified by the small return on the investment. Then came the greatest of all catastrophies to the industry, the World War. With the entry of the United States, slate quarrying was almost totally abandoned, being classed as unessential; labor was beyond reach. Immediately after our entry into the war the organization of the slate industry, so long projected and so long prevented by internal strife, took place to a considerable degree, and two large companies, were formed, one to deal with structural products, the other with roofing slate.

Slate production in the Lehigh-Northampton district is apparently again able to anticipate better days. General slate production in 1925 has risen over that of any year since 1917. Several quarries, hitherto abandoned, are being reopened. Although there was general industrial decline in 1921, slate suffered less than other commodities and roofing slate produced in 1928 experienced a sales increase over all previous years. Electrical slate has become an important factor in the development of the industry. The tendency to standardize specifications is noticeable now. All in all, despite the severe general depression of 1930-32, in which the slate industry has suffered as much as others, it seems as though slate were gradually regaining the relative industrial strength it possessed previous to the last war and in this the Lehigh-Northampton slate district, the leading one in the country, should be the chief beneficiary.

THE PEACH BOTTOM DISTRICT IN PENNSYLVANIA

EARLIER GEOLOGIC STUDIES

As early as 1858 Rogers studied the slate belt in Lancaster and York counties and discussed its slate production.¹ Subsequently the geologic features were described in far greater detail in the reports of the Second Pennsylvania Survey². Several shorter and later articles, which need not be mentioned here, have dealt with the areal geology, petrology, and physiography of the region. Very recently a thorough study of parts of York and Lancaster counties has been carried out by Knopf and Jonas³ and much of what is said about the general geology in the following description is taken from this source; the writer wishes especially to acknowledge his indebtedness to the two authors just mentioned.

There are several published descriptions of the Peach Bottom slate deposits, of which the more important, in addition to the reports of Pennsylvania Geological Survey already referred to, are mentioned

¹ Rogers, H. D., *Geology of Pennsylvania*, vol. I, p. 188, 1858.

² Frazer, Persifor, Jr., *Report of progress in the district of York and Adams Counties; Pa. Second Geol. Survey, Rept. C*, esp. pp. 77-143, 1876. Frazer, Persifor, Jr., *The geology of Lancaster County; Pa. Second Geol. Survey, Rept. CCC*, 1880.

³ Knopf, E. B., and Jonas, A. I., *Geology of the McCalls Ferry-Quarryville district, Pennsylvania; U. S. Geol. Survey Bull.* 799, 1929.

below.¹ In these it has been the common practice not to distinguish between the Pennsylvania and Maryland parts of the district.

LOCATION AND COMMERCIAL SETTING

Location and extent. The Peach Bottom slate district lies in Maryland and Pennsylvania, but only the Pennsylvania part is considered in what follows. Its north end is near Fairmount, Lancaster County, in the southeastern part of the State. Thence it extends southwest in a long, narrow belt, crossing Susquehanna River at Peach Bottom, passing through Delta, York County, Pennsylvania, and entering Maryland at Cardiff in Harford County, just south of the State line. The total length is about 13 miles, and the width in a northwest direction nowhere exceeds half a mile.

This area lies within three quadrangles of the Topographic Atlas of the United States, the Quarryville and McCalls Ferry, in Pennsylvania, and the Belair quadrangle, which is mostly in Maryland but extends about two miles into Pennsylvania along its north edge. Parts of the topographic sheets of these quadrangles have been used as bases for the map of the slate district.

Cities and towns. The dominant industry in the surrounding region is agriculture. Slate quarrying was once of far greater importance than now, but is responsible for the growth of several of the smaller towns. Two centers of noteworthy size, Cardiff and Delta, are in the southwest end of the belt here described; they are spread out along the highway for a distance of two miles across the Maryland-Pennsylvania line, Cardiff being in Maryland and Delta in Pennsylvania. In recent years their joint population has been approximately 1250. Northeastward, in or very near the outcrop of the slate, a line of lesser hamlets has grown up, West Bangor and Slate Hill in York County, and Peters Creek, Greene, and Fairmount in Lancaster County. Some twenty miles north of the slate belt are two large cities, in part manufacturing, in part distributing centers. York in York County (population 55,254 in 1930), and Lancaster in Lancaster County (population 59,949 in 1930). The slate belt lies approximately 60 miles west of Philadelphia and 35 miles north of Baltimore, and these two cities have been and, to a lesser extent, still are important slate markets, though all their consumption of Peach Bottom slate is at present derived from south of the Maryland line.

Transportation facilities. The Maryland & Pennsylvania Railroad connects Delta and Cardiff with York and Baltimore and thus affords an outlet for the western part of the district. East of the Susquehanna a branch of the Pennsylvania Railroad offers shipping facilities from Peters Creek and Whitaker in the slate belt to Harrisburg, Philadelphia, and Baltimore, via connections on the same line.

Susquehanna River flowing across the southwestern part of the dis-

¹ Hawes, G. W., and Others, Report on Quarries: 10th Census of the U. S., vol. X, part 3, pp. 172 and 178, 1880. Merrill, G. P., and Mathews, E. B., The building and decorative stones of Maryland: Md. Geol. Survey, vol. 11, part II, pp. 215-231, 1898. Merrill, G. P., Stones for building and decoration, John Wiley and Sons, New York City, 1910, pp. 184-186. Ferguson, E. G. W., The Peach Bottom slate deposits, Pennsylvania: Mining World (Chicago), vol. 33, pp. 183-184, 1910. Dale, T. N., Slate deposits in the United States: U. S. Geol. Survey Bull. 586, pp. 110-115, 1914.

trict, is not used for transportation. It is crossed by a ferry at Peters Creek. Its recent impounding by a power dam downstream has resulted in the flooding of those lower lying parts that border on the river.

PHYSIOGRAPHIC FEATURES

Viewed as a whole, the region is a sub-maturely to maturely dissected upland, the South Valley Hills of Knopf and Jonas¹. This is cut by the Susquehanna River whose major tributaries meander in intrenched valleys and form a dendritic or random drainage pattern. The larger tributaries of the Susquehanna—Muddy Creek and Broad Creek on the west, Fishing Creek and Peters Creek on the east—have cut well below the generally even crest-lines of the divides.

In detail, the greatest relief is at the edge of Susquehanna River; in the slate region river level is at 100 feet and high points half a mile from the water's edge rise to slightly over 400 feet. The lesser streams have relatively steep gradients and flow in narrow, youthful gorges. Away from the river and transverse to its course, the general level of the country rises from the 400-foot altitude at the rate of about 40 feet per mile to fairly uniform elevations of 500 feet on the divides.

West of the Susquehanna a ridge trending southwest rises above the general upland level, its continuation into Maryland attaining, two miles southwest of Cardiff, altitudes of as much as 660 feet. This is the "slate ridge" and it marks the outcrop of the slate-bearing formation and the accompanying resistant quartzite. Some of the steepest bluffs of the river valley are where it is transected by the Susquehanna. East of the river no such pronounced topographic difference indicates the areal distribution of the slate, although a line of occasional 600-foot summits between Whitaker and Bethel Church shows to the observant eye where it outcrops.

The flat summits or gentle slopes of the upland divides as a whole are well adapted to farming, but the steep-walled ravines are generally thinly timbered and not under cultivation. The slate ridge is little farmed and its crops are poor in contrast with the lush fields of the lower-lying upland on either side; this is primarily a result of the poor soil, largely lacking in lime.

GENERAL GEOLOGY

SUMMARY

The stratigraphic sequence in the general region includes, according to Knopf and Jonas,² rocks of pre-Cambrian age, which have been thrust up over Paleozoic rocks. The thrust plane lies north of the slate region, and in the latter the formations exposed are only three in number, all of which are probably pre-Cambrian (Algonkian) in age. The sequence in the immediate vicinity of the slate belt is therefore as follows:

¹ Op. cit., p. 7, 1929.

² Op. cit., pp. 18-41, 74-75, 1929.



A. Gently rolling topography north of Slate Ridge, developed on Peters Creek schist.



B. Slate Ridge from east of the Susquehanna; the higher land midway in the picture is underlain by slate, on both sides of which is lower topography underlain by schist.

| | Thickness, feet |
|--|-----------------|
| Peach Bottom slate: Dark blue-gray slate and slaty schist, with rare sandy interbeds near base | 1000 |
| Cardiff conglomerate: Quartzitic or faintly schistose conglomerate, with occasional quartzite beds | 200 |
| Peters Creek schist: Chloritic and sericitic quartz schist with interbedded quartzitic layers | ? |

These thicknesses are approximate only.

The rocks have been closely folded, but the general structure is a large syncline with a northeast trending axis, the Peters Creek schist being on the flanks and the Peach Bottom slate in the middle and preserved from erosion by infolding. Along the north side a fault has cut out the Cardiff conglomerate between the two other formations. This structure may have been related to the great thrust fault ("Martie overthrust") mentioned above, which is dated as later than the Middle Ordovician and earlier than the Triassic, the presumption being that it was chiefly formed in late Permo-Carboniferous times and coincided with the earlier part of the Appalachian revolution¹. A part at least of the folding may well have been far earlier, either during or at the close of the pre-Cambrian or in the earlier part of the Paleozoic era (post-Ordovician or middle Devonian).

The three formations are cut by dikes of diabase of Triassic age. The subsequent record is wholly physiographic and does not merit summarizing. Glaciation did not extend this far south and valley gravels are not of importance in the region; the only cover above bed rock is therefore that produced by weathering.

STRATIGRAPHY

Peters Creek schist. Areally this formation borders both sides of the slate belt. Its type locality is along Peters Creek at Peach Bottom, in Lancaster County. It is described by Knopf and Jonas² as a "series of chloritic and sericitic quartz schists interbedded with chlorite-sericite schist and grading toward the top into mildly metamorphosed quartzose and conglomeratic sediments."

The best exposures are in road and railroad cuts north of the slate syncline. Here the schist varies from gray to green in color, but is generally a dull olive-gray. These greenish tints contrast strongly with the dark blue-gray or black of the Peach Bottom slate. The schist is characteristically banded, a feature due to the alternations of white quartz and feldspar rock with olive-green chlorite-sericite bands. Generally such bands are less than half an inch thick, but locally, as near the schoolhouse half a mile south of Peach Bottom, they become much wider, attaining 2 or 3 inches; in such cases conglomeratic facies are common. The schistosity is parallel to the banding, and the schistosity planes have a pronounced sheen, due to the chlorite and sericite. Magnetite and a carbonate are prominent in thin sections examined by the writer. Near Delta in place of the schistose rock typical of the Peters Creek formation a serpentine is developed, which is being quarried as "green marble" at Delta.

¹ Knopf, E. B., and Jonas, A. L., op. cit., p. 79, 1929.

² Op. cit. p. 36, 1929.

From areal and structural considerations, the Peters Creek schist is inferred by Knopf and Jonas to be of pre-Cambrian age. It passes upward gradationally into the Cardiff conglomerate.

Cardiff conglomerate. This formation surrounds the outcrop of the Peach Bottom slate in an elongate, canoe-shaped pattern, except for its absence on the north side of the slate syncline where it is inferred to have been cut out by a fault. In general the outcrop does not exceed 300 feet in width, except at the east end of the syncline north of Fairmount. Like the slate the formation is resistant to weathering, and this property contributes to the topographic elevation of the slate ridge.

The Cardiff conglomerate consists of massive alternating layers of conglomerate and quartzite. Locally the conglomeratic layers are absent or greatly reduced, as near the schoolhouse one quarter of a mile east of Whiteford, Maryland. The formation where fresh is light gray, marked with the white blotches of quartz pebbles, often as much as an inch in diameter. These generally show elongation and flattening parallel to the schistosity. Occasional primary grains of albite are reported by Knopf and Jonas¹, and suggest that the conglomerate was derived from a feldspathic igneous rock. The larger pebbles show strain shadows and are well mortised, which indicates secondary growth. The matrix consists of sericite and rarer chlorite flakes, generally disposed parallel to the bedding, as well as much fine-grained quartz, originally sand. The rock possesses poor cleavage parallel to the bedding planes, which are lustrous with sericite. In places, as in the stone quarry one mile southeast of Cardiff, the conglomerate shows fissility, in the form of closely spaced fractures cutting directly across the quartz pebbles and meeting the bedding approximately at right angles.

The thickness of the formation is not given by Knopf and Jonas. As exposed on the south limb of the syncline on the two banks of Susquehanna River, it is estimated by the writer at 200 feet.

Upward the Cardiff conglomerate grades into the Peach Bottom slate.

There is some doubt as to the age of the Cardiff conglomerate and the overlying slates. The alternative possibilities are Ordovician and Algonkian. Knopf and Jonas regard both formations as Algonkian.

Peach Bottom slate. This formation is almost uniformly a dark gray or blue-black slate, verging on schist. It possesses good cleavage, which however, is locally wrinkled, especially near its contact with the underlying Cardiff conglomerate and at the easterly end of its outcrop (see map). The difference between the slaty and schistose facies consists chiefly in the wrinkling of the planes of slaty cleavage, often accompanied by the development of false cleavage in the schist. The cleavage surfaces have a high luster and show no traces of bedding, the chief irregularities consisting of minute protuberances (quartz-rich areas). On greatly prolonged weathering they assume first a dull olive-gray and later a reddish brown hue.

The lower layers of Peach Bottom slate bear quartzitic interbeds, rarely more than half an inch thick. These are well seen in several old quarries on the Jones estate half a mile south of the town of Delta and

¹ Op. cit. p. 38, 1929.

again on the north limb of the syncline in the railroad cut along the east bank of the Susquehanna.

Microscopically the Peach Bottom slate may be briefly described as a fine-grained slate consisting of flakes of muscovite and elongated grains of quartz, with some chlorite. Graphite and conspicuous andalusite crystals are also important constituents. A more detailed description of the mineralogic composition of the slates is given beyond.

The total thickness of the formation has been estimated at 1000 feet¹.

At one time, on the basis of obscure markings thought to be graptolites or algae, the formation was referred to the Ordovician². Its conformability and gradational contact with the Cardiff conglomerate, as well as the doubtful character of the supposed fossils and especially the larger areal and structural relations, have induced Knopf and Jonas to regard it as of Algonkian age.³

Where the slate has been somewhat more tightly folded, possibly in a period subsequent to the development of the cleavage, it approximates a schist, rather than a slate. Knopf and Jonas have very properly mapped these two facies, so nearly alike, as one formation, but for the economic purposes of this report an attempt, only partially successful, was made to outline the schistose areas.

STRUCTURE

General structure. The Peach Bottom slate, as interpreted by Knopf and Jonas, is preserved in a syncline ('Peach Bottom syncline'), with closely appressed limbs, broken on both sides of Susquehanna River by a fault which throws the north side up and thus cuts out the underlying Cardiff conglomerate. In the region here discussed, the evidence for synclinal structure is supported by the section partially exposed along the west bank of Susquehanna River, where the slate ridge is crossed by the stream. This and the outcrops across the river furnish the two best sections of the structure as a whole. The section on the west bank of the Susquehanna is not continuously exposed yet it expresses the regional structure in outline form. At the south end the rock is a quartz schist, with a dip of 70°S. , whereas the cleavage dips only 55°S. ; this is therefore the south limb of a northward overturned syncline. At the Slate Point quarry, which overlooks the river bluff, the beds appear to dip 80°S. , and the cleavage dips in the same direction but at a lower angle. Approximately 500 feet north of the strike-continuation of the beds just described, the bluff near river level shows beds which are composed of alternate layers of slate (averaging 6 inches thick) and quartzitic slate (1' 32" thick). These beds dip 70°S. , whereas the cleavage stands vertical; the structure here is thus evidently the north limb of a syncline, the axis of which must pass between this outcrop and the Slate Point quarry.

On the east bluff of Susquehanna River along the railroad the slate shows close crumpling. All bedding-cleavage relations observed indicate the south limb of a northward overturned syncline, but the north limb is not observed, though there is a suggestion of a fold axis near

¹ Knopf, E. B. and Jonas A. L., op. cit., p. 39, 1929.

² Frazer, Persifor, Jr., The Peach Bottom Slates of Southeastern York and Southern Lancaster counties: Am. Inst. Min. Eng., Trans., Vol. 12, p. 358, 1884.

³ Knopf and Jonas, op. cit., table opp. p. 68, 1929.

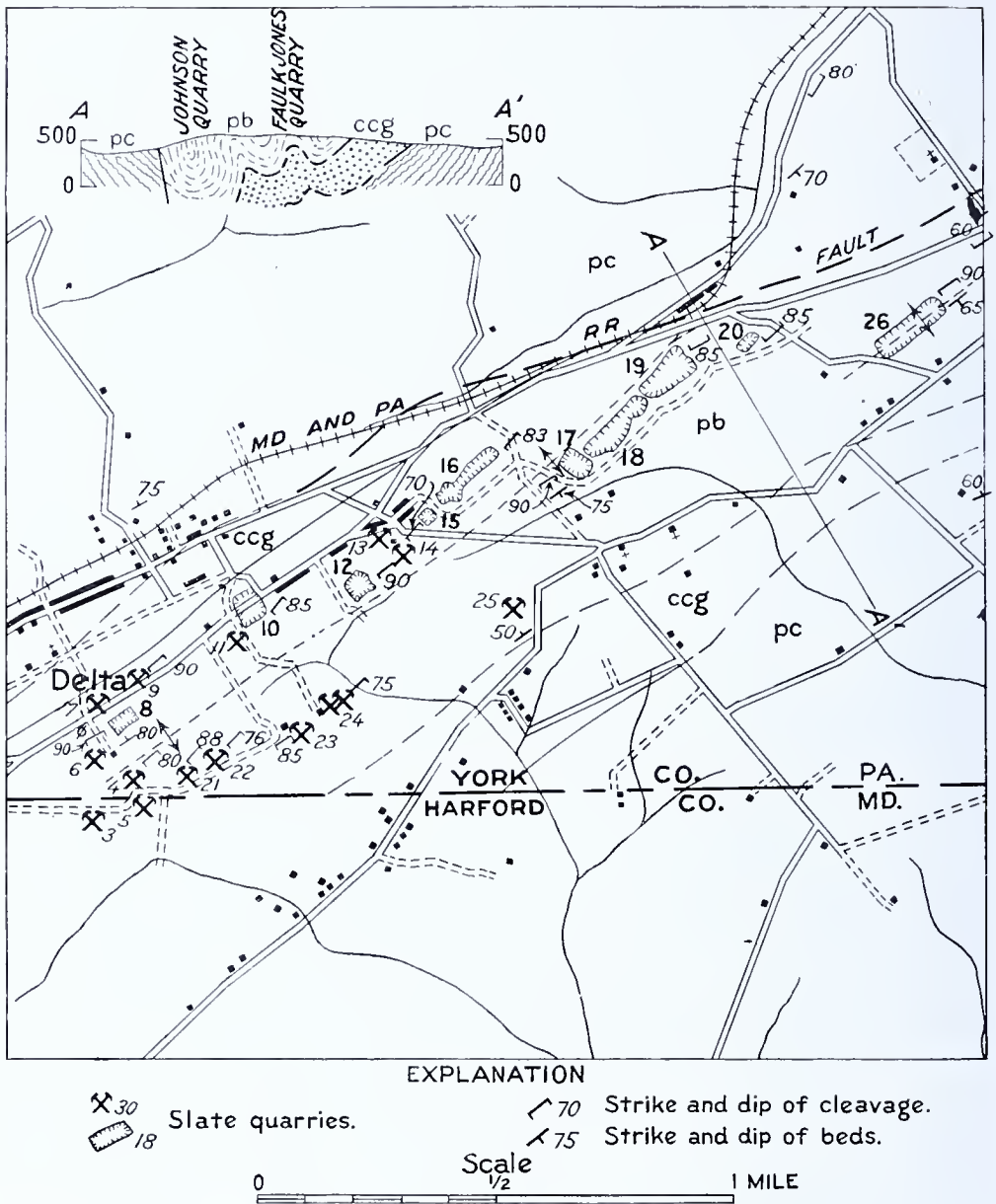


Fig. 84. Detailed map of west part of Peach Bottom district from Pennsylvania state line east to Faulk Jones quarry. After Knopf and Jonas, modified by C. H. Behre.

the north end of the slate exposure in the cut. The axial plane of the structure is presumably parallel to the cleavage, which strikes N.50°E.

The evidence for the fault along the north edge of the slate belt is twofold. First, it is noted that the Cardiff conglomerate, ordinarily a conspicuous formation, does not appear north of the syncline for a distance of about nine miles, between a point a mile east of Delta and another a little more than a mile east of the Fairmount school. Yet the conglomerate is seen both east and west of the stretch of country mentioned, along the strike continuation of the line indicated, in its proper position between slate and schist. Where it crosses Susquehanna River

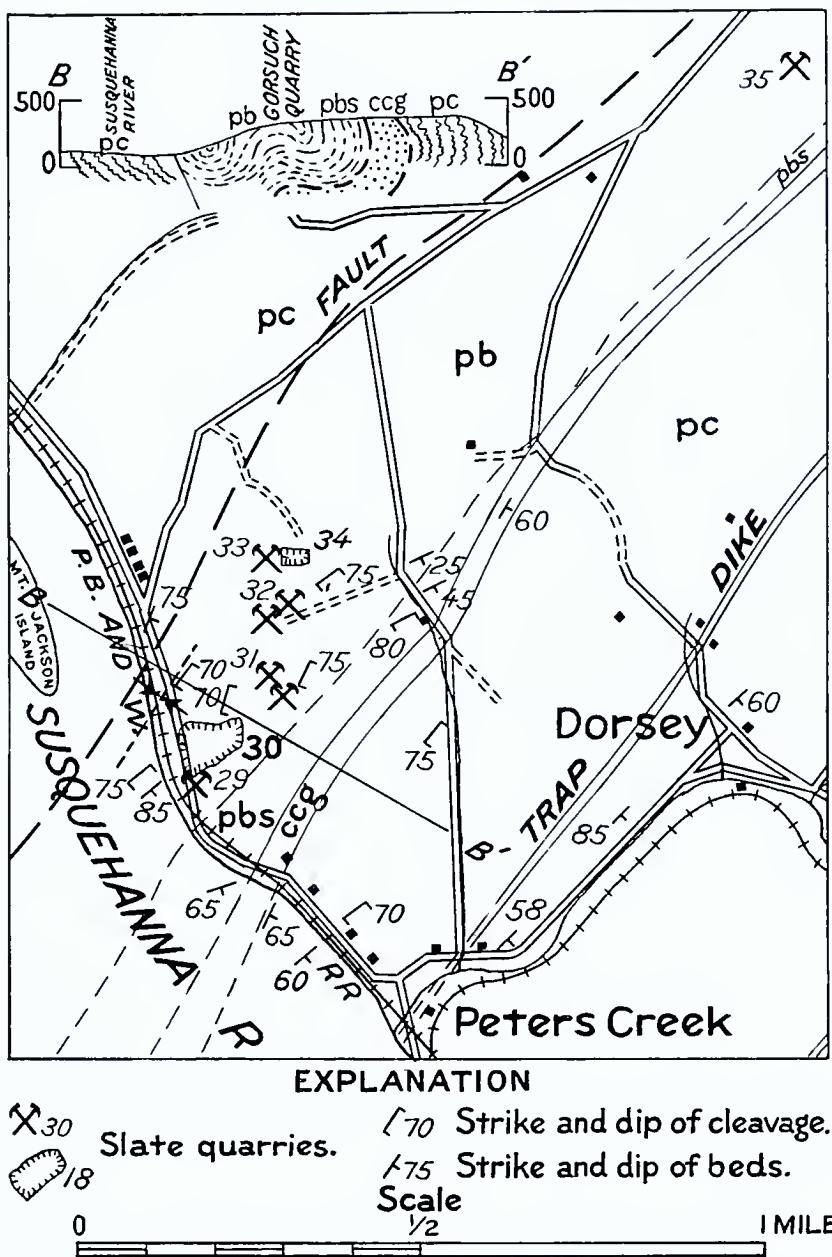


Figure 85. Detailed map of Peach Bottom district near Susquehanna River.

the fault cuts out not only the entire Cardiff conglomerate, but probably also a part of the Peach Bottom slate as well, inasmuch as the north limb of the Peach Bottom syncline with the beds dipping at similar angles, has only half the width of the south limb. The stratigraphic displacement of the fault may here be estimated to be at least 450 feet and is probably more, inasmuch as the outcrop of the Peters Creek schist may also have been narrowed somewhat along the fault plane. The second piece of evidence is that the cleavage, as well as the few doubtfully determined fold axes between Delta and Slate Hill, clearly strike into the boundary between Peach Bottom slate and Peters

Creek schist as it has been mapped north of the slate syncline; they are thus truncated by the fault.

In the absence of satisfactory criteria generally applicable for the recognition of beds, the details of the structure are very incompletely known. It was only in about ten very isolated localities that bedding could be recognized with certainty within the slate beds themselves. If the "slaunts" (see page 47) be taken to represent the bedding, then something more can be arrived at, but even this evidence is dubious. Much the same can be said of faulting in this district and for similar reasons. What follows in regard to the details of structure has therefore little more than a hope of correctness; statement of probabilities seems justified only because nothing better can be offered.

Folding. Evidence for the major syncline of the district has already been adduced. Its axial plane probably dips about 75° S. and strikes N. 50 - 55° E. where the structure crosses Susquehanna River.

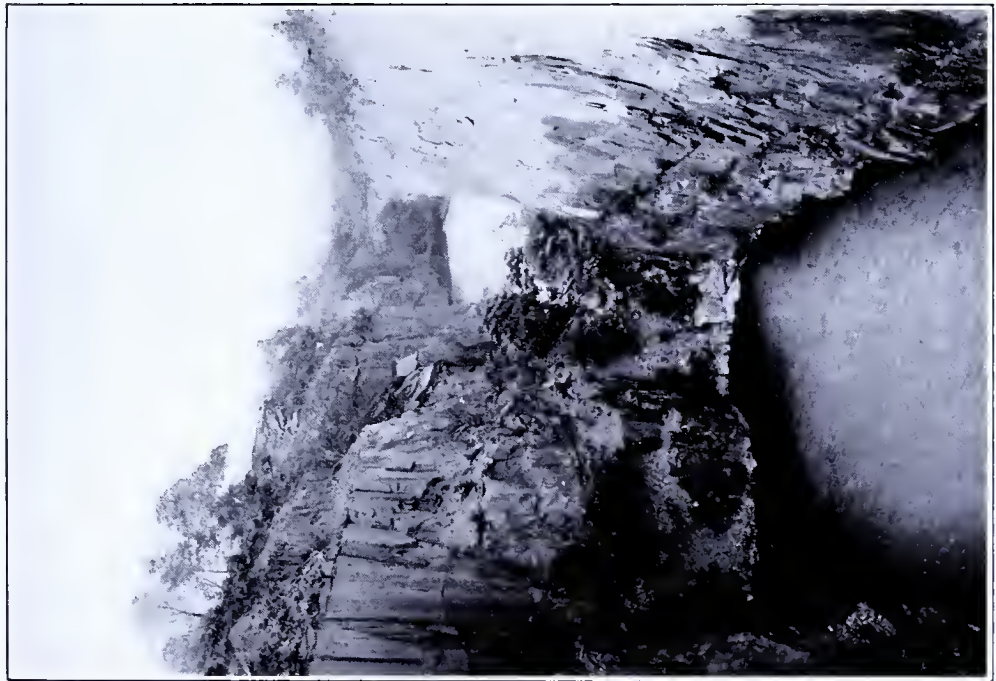
In detail, thanks to the excellent exposures created by quarrying, there are in the western part of the district indications of several minor folds. As previously stated, however, these minor structures must be accepted with reservations. The patterns suggested are essentially isoclinal; the axes strike about N. 55° E., with no very noticeable pitch. At the Miles quarry, about 4000 feet west of the West Bangor store on the Ridge Road, the cleavage strikes N. 55° E. and stands vertical, whereas prominent "slaunts" (beds?) strike N. 50° E. and dip 80° N. Yet about a thousand feet south on the Hughes Estate, is a quarry in which very thin sandy (now quartzitic) layers show, dipping 65° S., whereas the cleavage dips 10° more steeply to the south. An anticlinal axis may thus be inferred to lie between these two openings, but its exact position is uncertain. Probably the same axis is immediately north of the McLaughlin quarry, half a mile east of the West Bangor store, for in this opening "slaunts" dip steeply southeast while the cleavage stands vertical. Similar relations obtain in the R. L. Jones quarry.

A series of curved parting planes strongly suggesting bedding is shown in the northeast wall of the Faulk Jones quarry and may be interpreted as indicating an anticline axis parallel to the longer dimensions of the quarry and between its walls.

Excellent examples of small, close folds, almost isoclinal in pattern, show in the railroad cut on the east side of Susquehanna River.

Faulting. The major fault of the district, that along the north flank of the Peach Bottom syncline, has already been described. Minor fault planes are all of an indefinite nature, yet there are locally strong suggestions of movement. Thus, calcite-coated joint planes with striae are frequent. A slab from the Humphrey quarry showed two sets of striae roughly normal to each other. Small-scale thrust faulting also occurs with the folding mentioned in the railroad cut on the east bank of Susquehanna River. But much more prominent zones of movement are also seen.

Thus, in the McLaughlin quarry a shattered zone, dipping steeply south and two inches wide, is well exposed in the northeast wall. There is clear evidence of movement in this zone, one of its walls being lined with typical fault gouge, which is separated from the other wall by a



A. Humphrey quarry, looking east along strike; note vertical dip of cleavage.



B. R. L. Jones quarry, looking northeast along strike; the planes dipping steeply to left are "slants" (bedding?); the vertical planes are cleavage.

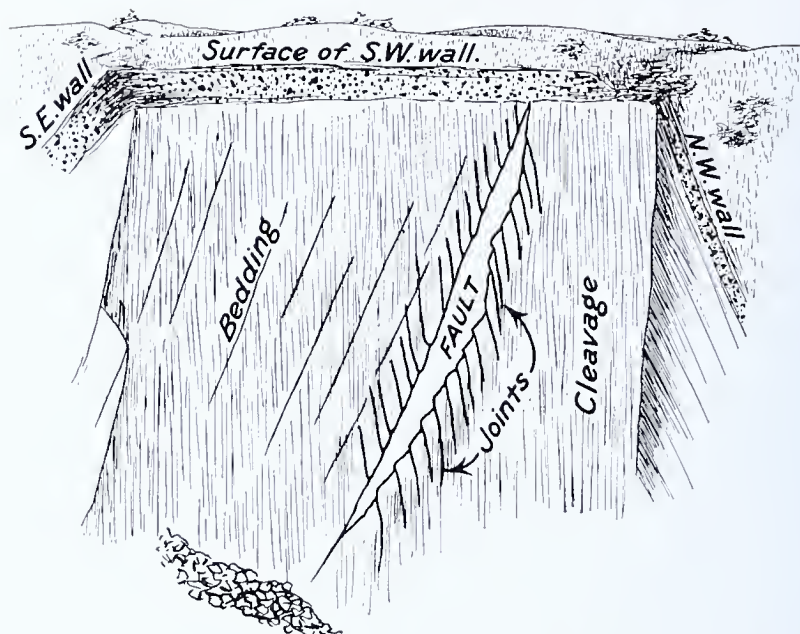


Figure 86. Sketch of southwest wall of the McLaughlin quarry, to show relations between bedding (?), cleavage, fault, and the closely-spaced joints related to the fault; see also text.

crevice an inch wide. On both sides of the zone of movement there are small joints that dip more steeply. This plane is neither strictly parallel to the "slaunts" (bedding?) nor to cleavage.

In the Gorsuch open cut on the east bank of the Susquehanna, near the middle of the northeast wall a heavily shattered, quartz-veined zone strikes and dips roughly parallel to the cleavage. Structurally it resembles some of the slips parallel to cleavage which are known in the "hard" slate of Northampton County and have been described on page 169.

Cleavage. The cleavage of the Peach Bottom district is remarkably regular; it shows but little curvature and the strike varies only slightly from northeast. The average of accurate readings in 30 quarries gives a strike of 44° E., with variations from $N.28^{\circ}$ to 55° E.; average dip is 83° S., and dip readings fluctuate between 80° N. and 65° S. In a general way it may be said that cleavage swings more northerly as the east end of the district is approached.

Close folding of cleavage is seen in association with shear zones (see page 372). Large-scale, very gentle curvature is not general, but locally it is observed, as in the Gorsuch open cut, east of Susquehanna River; here the cleavage at the surface dips 70° S., but curves gently so as to dip 80° N. 35 feet lower down.

In places the cleavage surfaces are roughened by tubercle-like elevations a millimeter or less in diameter. Examples are seen at the Shank quarry. Microscopic study shows that they consist of lenticular aggregates of quartz, chlorite, and sericite, of which the quartz seems to be the latest in origin.

False cleavage. False cleavage shows conspicuously in much of the district. As usual it is generally associated with cleavage curvature,

PLATE 66.



A. Northwest wall of Humphrey quarry, showing three zones of almost horizontal jointing.



B. Northwest wall of Faulk Jones quarry, showing almost horizontal joint zone.

or with closely spaced and frequently minute wrinkling. This latter is a feature especially well-developed in the Peach Bottom slate along its eastern edge, as though resulting from drag by the underlying quartzite in folding which was later than the cleavage. Under the microscope, however, strangely enough, the planes of false cleavage are most pronounced on sections at right angles to the grain. The inference would thus seem to be justified that false cleavage in the Peach Bottom district is due to stresses transverse to the cleavage strike, probably largely the same as produce pitch in folds. In the absence of noteworthy pitch in the district, this explanation is highly unsatisfactory, yet it seems to be the best at present available in view of limited knowledge.

Cleavage shear zones. This feature is lacking in the district, so far as observed, but cleavage that has been thrown into folds shows in several places in the Peach Bottom formation, notably along the southern edge of the belt, near its contact with the Cardiff conglomerate. Examples are seen on the road about half a mile southeast of the church at Greene and again in the southerly end of the railroad cut north of Peach Bottom Station on the east bank of the Susquehanna. Near joints, too, there has been local shearing of the cleavage, as at the Bon-sell quarry, a short distance east of the Gorsuch open cut on the Pennsylvania Railroad.

Grain. In the Peach Bottom district, as elsewhere, the grain trends about $N.45^{\circ}W.$, or approximately at right angles to the cleavage. The irregular grain planes stand generally nearly vertical, but are ill defined, as is usually the case.

Microscopic studies show that in thin sections of Peach Bottom slates cut parallel to the cleavage the grain direction is indicated by an elongation of mica and chlorite flakes. This feature is especially well shown with the aid of the gypsum plate, remembering that with the mica flakes in the cleavage plane the dimensional elongation of the particles is parallel to 100, and that $b = \text{optical gamma}$. Generally the elongation of chlorite with respect to its optic axes is apparently similar to that of the mica in sections in the slaty cleavage plane. Even magnetite and graphite masses tend to show elongation parallel to the grain. As usual in sections at right angles to both cleavage and grain the chlorite and mica crystals are shorter than in sections in the grain plane.

Jointing. In the district as a whole, northwest striking joints predominate (see Figures 87, 88). However, northeast joints are also present, though in subordinate numbers. There is a conspicuous lack of joints, other than the "slants" (bedding plane partings?) already referred to, that strike parallel with the strike of beds or cleavage.

The dips of joints are most commonly vertical or nearly so. An example of dip systems is given in Figure 89, which represents graphically and in somewhat generalized fashion the joints measured in a single large opening. Two systems are seen, traces of both of which persist over the entire region, although the steeper dips are the more prominent, as a rule.

In most quarries there are also present one or more (for example, three in the Humphrey quarry) fairly flat shattered or jointed zones

at which other joints generally stop,—whether through offset or because they do not reappear on the other side of the flat joint is uncertain. These are the “big flat” joints of quarrymen. They are not unwarped planes, like most of the other joints studied, but are wave-

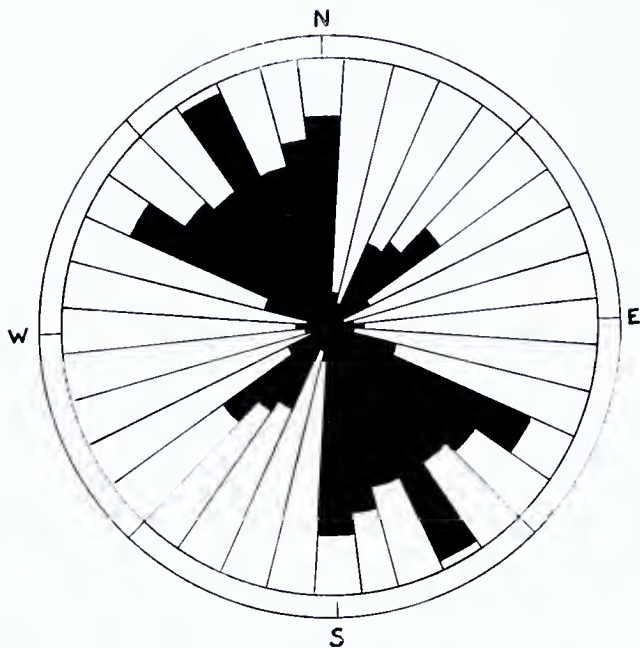


Figure 87. Joint strikes in all Peach Bottom quarries,—178 observations; distance from center of circle to periphery represents 25 observations, and radii of sectors proportional.

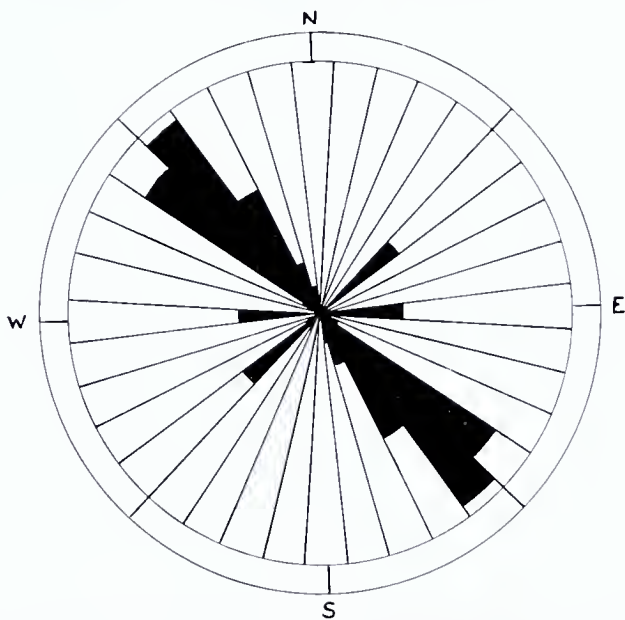


Figure 88. Joint strikes in Peach Bottom-Peerless quarry, south of Maryland state line; total of 62 observations; distance from center of circle to periphery represents 18 observations, and radii of sectors proportional.

like, rising gently here and falling there; they form wide openings locally. Upon weathering, the rock turns a deep hematite red and the joint space is apparently widened and contains a clay of that hue. The operators believe that the slate below such a joint is better than above it. This, if true, is probably due in part to greater oxidation above, for

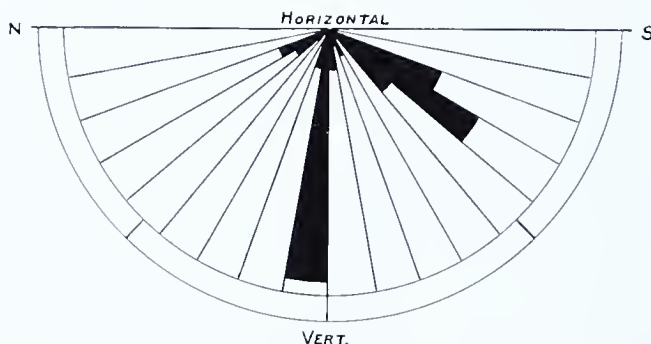


Figure 89. Dip of joints in a Peach Bottom quarry.

the joint must serve as a watercourse and thus reduces free circulation of air beneath it. It also seems probable, from a few observations made by the writer, that most joints stop against the "big flat" joints, and hence that the slate below the "big flat" joints is in cases freer of fracture than that above it.

GEOLOGIC HISTORY

As far as the local record goes, the geologic history can be summarized very briefly¹. In Algonkian times the sea covered the area and in it were deposited calcareous muds, grading upward into quartzites and conglomerates, and these in turn giving way to purer, slightly siliceous muds,—respectively, the Peters Creek schist, Cardiff conglomerate, and Peach Bottom slate of the future. Toward the close of the Algonkian era igneous intrusions cut the rocks of this approximate time period, not in the immediate region here described, but near by. This intrusion was accompanied by folding, which metamorphosed all three formations of the Peach Bottom district to at least a moderate degree.

Subsequently the region was probably covered by Paleozoic sediments. These were, in turn, folded and moderately metamorphosed at least once at the close of the Paleozoic era, and perhaps earlier in the Paleozoic as well. If the interpretation of Bliss and Jonas is correct the Paleozoic rocks now underlie the Algonkian through faulting which took place at one of these periods of compression. The Algonkian rocks of the Peach Bottom district have therefore suffered compression and metamorphism at two (or more) times. It is thus uncertain what proportion of the folding, faulting, and metamorphism now recorded in these older rocks is to be assigned to each period of compression. Since Paleozoic times, the history of the region has been wholly one of erosion, with the exception of the intrusion of dikes of basic igneous rocks in the Triassic period.

¹ Knopf and Jonas, op. cit., pp. 81-90, 1929.

COMPOSITION OF THE SLATE

CHEMICAL COMPOSITION

Below are given five analyses of Peach Bottom slate. It is believed that the slate from the Peerless quarry, which is in the Maryland part of the district, is representative of the Pennsylvania Peach Bottom slate as well. Analysis 5, to judge by its abnormally high alumina and low silica contents, is probably not truly representative of the district as a whole. Figures represent per cent of total.

Analyses of slates from Peach Bottom district

| | 1 | 2 | 3 | 4 | 5 |
|------------------------------------|-------|--------|-------|-------|-------|
| SiO ₂ | 55.88 | 58.37 | 60.32 | 60.22 | 44.15 |
| TiO ₂ | 1.27 | tr. | n.d. | n.d. | n.d. |
| Al ₂ O ₃ | 21.85 | 21.99 | 23.10 | 19.56 | 30.84 |
| FeO—Fe ₂ O ₃ | 9.03 | 10.66 | 7.05 | 5.24 | 14.87 |
| CaO | 0.16 | 0.30 | ... | 3.87 | 0.48 |
| MgO | 1.50 | 1.20 | 0.87 | 2.30 | 0.27 |
| K ₂ O | 3.64 | 1.93 { | 3.83 | 2.90 | 4.36 |
| Na ₂ O | 4.46 | } { | 0.49 | 2.15 | 0.51 |
| CO ₂ | n.d. | 0.39 | n.d. | n.d. | n.d. |
| FeS ₂ | 0.05 | n.d. | 0.09 | n.d. | n.d. |
| C | 1.79 | 0.93 | n.d. | n.d. | n.d. |
| Water above 100°C. | 3.39 | 4.03 | 4.08 | n.d. | n.d. |
| Loss on ignition | n.d. | n.d. | n.d. | 7.45 | 4.49 |
| SO ₃ | .02 | n.d. | n.d. | n.d. | n.d. |
| S | n.d. | .11 | n.d. | .30 | n.d. |
| MnO | .58 | tr. | n.d. | n.d. | n.d. |

n.d.—Not determined.

1. Slate from Humphrey quarry, near Delta: Pa. Second Geol. Survey Rept. CCC, p. 270, 1880. A. S. McCreath, analyst.
2. Slate from York County, quarry not given: U. S. Geol. Survey 20th Ann. Rept., Part VI, cont., p. 399, 1899. Booth, Garrett and Blair, analysts.
3. Slate from Lancaster Co., Pa.: Merrill, G. P., Rocks, rock weathering and soils, McMillan Co., New York, 1906, p. 119.
4. Slate from the John W. Jones (Peerless) quarry, Harford Co., Maryland. C. L. Lancaster, analyst.
5. Slate from the John W. Jones (Peerless) quarry, Harford County, Md.: Md. Geol. Survey, vol. II, p. 226, 1898. G. P. Merrill, analyst (See also Merrill, G. P., Rocks, rock-weathering, and soils, McMillan Co., New York, 1906, p. 119). The unusually low silica and high alumina cast doubt on these figures.

In general these slates are higher in silica than the slates of the other Pennsylvania districts (see page 174). They also contain noticeably more iron oxide, but are lower in lime and magnesia, and, in those cases where it is reported, in pyrite. The far smaller loss in ignition suggests also a smaller content in carbonates and water. Microscopically this last conclusion is well supported by the almost total absence of visible carbonate particles and the generally more compact texture, which favors the exclusion of interstitial or absorbed water.

MINERALOGICAL COMPOSITION

Many thin sections of the commercial slates of the Peach Bottom district were examined microscopically. With medium power they show a uniform and finely granular sericite-quartz rock, with good orientation on the part of the mineral constituents. The ground mass is dominantly muscovite (sericite), with lesser quantities of quartz, andalusite and graphite, and much smaller amounts of chlorite, pyrite (very prominent in some sections), magnetite, rutile and zircon. (Car-

bonates are absent. Tourmaline, though mentioned by Dale¹, was not seen by the writer. Sections in the plane of the cleavage are dark, due to graphite, and show a meshwork of flakes and thin stringers of sericite more or less oriented with the long axes parallel. The orientation is roughly estimated at from 75 to 90 per cent perfect for 90° sectors: that is, out of any 100 individual flakes between 75 and 90 have their longest dimensions varying not more than 45° from a direction of maximum parallelism. Occasional lenses of quartz and sericite form a clearer matrix here and there, in the approximate center of which there are commonly to be found either lath-like crystals of andalusite that do not exhibit linear parallelism or areas of quartz without noteworthy strain shadows and evidently secondary in origin. The quartz lenses without andalusite are especially prominent in those specimens that show tubercle-like projections on the cleavage surfaces (see under Cleavage, page 370). Slate described by the quarrymen as conspicuously hard bears more quartz grains than the softer slate, as might be expected.

Sections at right angles to the cleavage plane show excellent orientation of mica flakes and pronounced elongation of quartz, these being the two principal minerals that determine the cleavage planes. Lenses with sericite, quartz, and andalusite crystals are again common and possess marked dimensional elongation in the direction of the cleavage. In such lenses the andalusite crystals are commonly accompanied by flakes of sericite which have their longer dimensions parallel or sub-parallel to those of the andalusite individuals. In sections at right angles to cleavage there is little difference in appearance, whether cut parallel or at right angles to the grain plane: the latter more commonly show deformation by development of false cleavage, and this is the chief distinction. In the tiny false cleavage folds the mica flakes are bent and deformed. In places the entire sigmoid flexure of mica along a false cleavage plane is crossed by a single, undeformed andalusite crystal, the individual mica flakes actually being pushed apart by the andalusite, which is thus clearly shown to be later in development than the false cleavage.

DETAILED DESCRIPTION OF MINERALS.

Sericite or secondary muscovite. Of two types:

1. Elongated parallel to the cleavage. Shows faint yellowish pleochroism. In sections cut at right angles to cleavage shows as long, almost hair-like strands. The ratio of length to breadth in these strands averages 12:1; they taper from a widest part, roughly near the middle. In sections in the plane of the cleavage, they are elongated parallel to 100, the ratio between length and width giving a smaller figure than that quoted above.

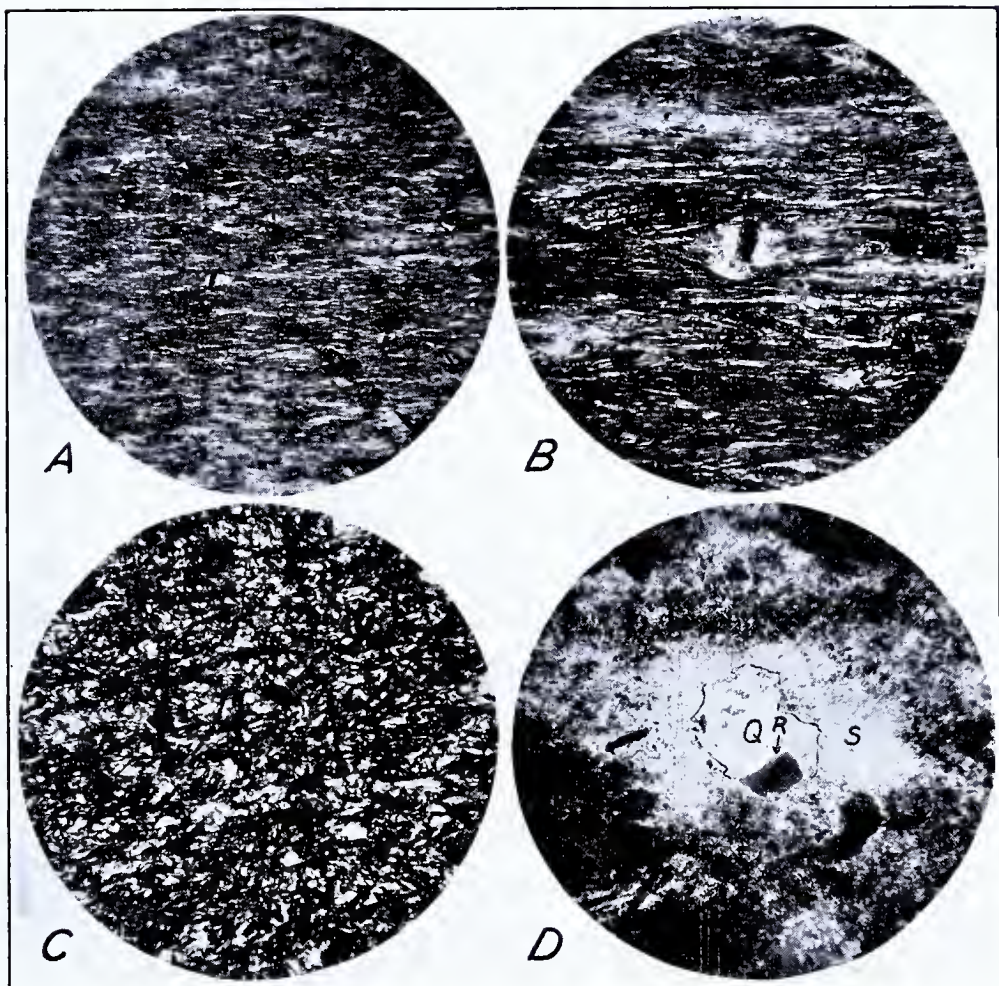
2. In lenses, with fibers generally inclined to the cleavage, probably in the nature of crystalloblasts, as no definite orientation is observed. These fibers are generally shorter than the other type, and broader, with ends sharply truncated. Dimensions of individual flakes in such cases average about .06 mm. by .012 mm. Commonly such sericite forms with elongation parallel to that of the andalusite, as described above.

Quartz. Of three types:

1. Grains showing as elongated lenses in sections in the plane of the grain but with much less elongation in sections at right angles to cleavage and grain. In the former, the dimensions vary, but larger lenses measure up to .1 by .2 mm. These individuals exhibit very fine feathering out at their ends, few strain shadows, and perfect or nearly perfect parallelism in orientation. Their direction of elongation is at right angles to crystallographic *C*. (Trener's law) hence under the microscope they can be readily recognized with the aid of the gypsum plate. The evidence sug-

¹ Dale, T. N., *Slate in the United States*: U. S. Geol. Survey Bull. 586, p. 114, 1914.

PLATE 67.



Photomicrographs of Peach Bottom slate. A. Section transverse to cleavage, John Humphrey quarry; cleavage and general elongation from left to right; andalusite porphyroblasts, surrounded by "segregation zones," with elongation across cleavage; x 16 diams.; B. Section transverse to cleavage, John Humphrey quarry; andalusite porphyroblasts in sericitic ground mass; note the clear "segregation zone" surrounding the andalusite individual, the cleavage flakes curving around the latter; x 140 diams.; C. Section at right angles to cleavage and grain, Fank Jones quarry; irregular texture produced by extreme development of false cleavage; x 25 diams.; D. Section in plane of cleavage, Shank quarry; central, clear area of quartz (Q), containing a large, sub-rectangular rutile aggregate (R), and surrounded by faintly cloudy basal sections of sericite (S); these minerals form a "knot" in the section; x 130 diams.

gests that they are largely or wholly secondary, despite the lenticular form suggesting primary quartz grains flattened by recrystallization. In some sandy phases quartz of this type attains large sizes and bears inclusions of sericite and andalusite; such quartz areas show strain shadows.

2. Small, rounded grains, rarely seen except in the sandy layers. They frequently show strain shadows. These are interpreted as primary quartz grains. At their edges projections suggest secondary growth around the nucleus, similar to that commonly observed in quartzites.

3. Thin, ribbon-like or irregular areas, ending in fringes which project between the sericite strands; these surround the andalusite individuals and seem to represent

secondary segregations arising through alteration from sericite (in which the ratio of alumina to silica is 1:2) to andalusite (alumina : silica as 1:1).

Andalusite. This mineral appears in columnar crystals, which are unoriented with respect to the cleavage. In size individuals average about .08 by .02 mm., but are highly variable. They are full of inclusions, so that in places they are virtually opaque; as already noted by Dale¹, these are in part arranged diagonal to the long axis of the andalusite crystal. An examination of numerous thin sections has convinced the writer that such diagonal arrangement of impurities is due to resorption of the material of sericite strands, for the effect is most pronounced where the strands are cut by the andalusite (see Plate 67).

The clearer lenses that commonly surround the andalusite and bear sericite and quartz have already been mentioned.

Graphite. Occurs finely disseminated throughout the slate. Individual grains are very small, but the distribution is irregular and locally they are massed into very dark patches. This irregular distribution is even visible, though rarely, on the cleavage surface of the hand specimen.

Chlorite. This mineral is recognized occasionally by its abnormal interference colors. In the sections examined the pleochroism is very weak. The presence of chlorite in larger quantity than visible is inferred by the writer because it frequently shows, together with sericite, in the lenses mentioned, where, as with sericite, the longer dimension is unoriented with respect to the cleavage of the slate; in the finer particles of the ground mass it is virtually indistinguishable from the mica.

Pyrite. Present occasionally in small, irregular masses, but generally forming lenses, similar in shape and size to the andalusite crystals and easily confused with the latter. The long dimensions of the pyrite mass, however, like the sericite crystals, are almost always well oriented with respect to the cleavage. This suggests that the pyrite, though clearly secondary, is earlier, dating back to the same epoch as that of the sericite in the deformation of the rock.

The pyrite lenses reflect light as though composed of numerous small crystals and the occasional irregularity of their outlines suggests the same explanation. Where exposed they are one of the first minerals to be altered, rusting to limonite. This rusting may also account for the spots of lighter color occasionally seen on cleavage planes.

In a few places pyrite crystals up to a quarter of an inch on a side were seen, developing along joint planes in small vug-like depressions.

Magnetite. Forms irregular areas in some of the slate; the sizes are highly variable. Like the pyrite, these go over into hydrated iron oxide upon prolonged exposure, but much more slowly. In schists bordering the slate and rarely also in some of the sandy layers, sharply rectangular euhedra as much as .2 mm. on the side are seen.

Rutile. Best seen in sections in the cleavage plane. In irregular concretionary grains, composed of tiny crystals which are rosetted at 60° angles; in diameter they measure up to .08 mm. They suggest pseudomorphs, probably after magnetite. Similar rutile pseudomorphous after hematite is mentioned by Dana² and after ilmenite in Brazilian slates by Bramm³. Rutile needles are apparently wholly lacking, as pointed out by Dale⁴.

Zircon. Rounded grains of zircon are seen in a few thin sections. They are most common in the sandy beds associated with the slates.

ECONOMIC GEOLOGY OF THE SLATE

USE FACTORS

The Peach Bottom slate is unquestionably one of the best roofing slates in the world, and Peach Bottom roofing slate is still produced just across the State line in Maryland (by three operators in 1929 and 2 in 1930), but not in Pennsylvania.

Color and luster. The slate produced in this region has a higher

¹ Dale, T. N., *Slate in the United States*; U. S. Geol. Survey Bull. 586, p. 112, 1914.

² Dana, J. D., *The system of mineralogy*, 6th ed., John Wiley and Sons, New York, 1914, p. 238.

³ Bramm, Alfred, *Reconstitution process in shales, slates, and phyllites*; *Mineralogical Mag.* (London), vol. 19, p. 213, 1921.

⁴ Op. cit., p. 112, 1914.

luster and a little darker blue-gray color than any of the other commercial slates of Pennsylvania. It is near but slightly darker than the "neutral gray k" of the Ridgway color chart. The general absence of appreciable amounts of carbonates points toward unusual permanence in the colors. Fresh cleavage surfaces exhibit a pronounced luster which slowly disappears upon color-aging.

Locally the cleavage surface is spotted with light olive-gray circles one-eighth of an inch or less in diameter. These are seen on fresh fractures and so cannot well be attributed to weathering; they were not studied under the microscope, but they probably are the result of oxidation of pyrite lenses.

Upon very prolonged weathering, far in excess of that developed by ordinary use, the slate becomes olive-gray and finally a dull brown. Such colors or a still later deep hematite red are seen on the borders of joints or elsewhere on long-exposed surfaces.

Strength of the slate. Only a few comparative strength tests of Peach Bottom slate are available. These seem to show that it has an exceptionally high crushing strength, an average value of 11,260 pounds per square inch being Merriman's value for the mean of twelve tests of the crushing strength¹. This is much higher than for most other American slates. It is a noteworthy fact that specimens exhibited at the Crystal Palace exposition in England in 1850 were awarded the highest premium as the best roofing slate then known².

Variety of uses. Though the dark color, its uniformity, and its stability, as well as the strength of the Peach Bottom slate all combine to make it a highly desirable roofing slate, the variety of its uses is small. In comparison with the slates of the Lehigh-Northampton district, the Peach Bottom slate is sawed and planed with difficulty and the mill products are fewer. Grave vaults and covers, steps and risers are still manufactured, and in the past this business, notably at the Humphrey and other large quarries, has thrived, but for sinks and other carefully turned structures the slate does not seem to be so well adapted. In consequence the few active quarry companies have concentrated more and more upon the production of slate for roofing. This in turn reduces the volume of the business and increases the "overhead." Since 1927 only two quarries, both on the Maryland side of the line have been making slate. In Pennsylvania only a single company was in operation in 1928; this was crushing the slate to make granules.

About 1922 the Blue Mountain Stone Company leased 79 acres of slate land 1 mile northeast of Delta and began the manufacture of roofing granules. At first the waste dumps of an old slate quarry were used but for several years now the mill has been operated on freshly quarried slate. The rock passes through primary and secondary crushers, a drier, and screens. The granules are used for making roofing material and the dust is utilized for making the joints in imitation brick siding.

This plant is now operated by The Funkhouser Company of Hagerstown, Maryland, the parent of the Blue Mountain Stone Company, and has a capacity of 90,000 tons of granules annually.

¹ Merriman, Mansfield, The strength and weathering qualities of roofing slates; Am. Soc. Civ. Eng., Trans., vol. XXVII, pp. 331-319, 1892, and vol. XXXII, pp. 529-539, 1894.

² Ferguson, E. G. W., Peach Bottom slate deposits, Pennsylvania; Mining World (Chicago), vol. 33, p. 133, 1910.

OVERBURDEN

Glaciation did not reach southern Pennsylvania; hence weathering has in all places extended some distance down into the bed rock. Generally it is necessary, therefore, to remove at least 5 or 10 feet of highly weathered rock before slate can be produced. Fortunately for the quarryman, the slate weathers only very slowly, hence this weathered overburden is surprisingly thin. In no case was it observed to extend more than 20 feet below the surface.

EFFECTS OF BEDDING AND FOLDS

Except for the rare cases where actual sandy layers are present, the effects produced by bedding are not seriously deleterious to quarry operations. "Slaunts," if they may be regarded as bedding planes, are much like joints in the advantages and disadvantages to the quarryman. Since the formation is too homogeneous to permit the tracing of the beds, complications introduced by folding, such as affect quarry methods in the Lehigh-Northampton district, are not operative here.

EFFECTS OF SPECIAL STRUCTURAL FEATURES

Faulting. As usual, fault zones, which shatter the slate heavily because of its brittle character, cause serious losses in quarrying. The shattered zone previously described in the McLaughlin quarry (see pp. 368, 370) is an example. The slate at the immediate edge of the fault is, of course, utterly worthless. But the destruction generally also extends much farther out, because of the closely spaced joints that were developed accompanying the movement. In the case cited, a strip at least 8 feet wide on each side of the fault plane had to be discarded.

Cleavage. The steep dip of the cleavage prohibits the use of cleavage planes for quarry floors. The floor must therefore be developed on flat joints or, since these are not commonly available, must be cut directly across the cleavage.

False cleavage. For a discussion, see page 370, above. Unlike its effect in other slate districts studied, this feature does not seem to be seriously deleterious in Peach Bottom slates. If very closely spaced and possessing great amplitude, it may cause breaking of the slates into narrow strips, the sides of which are bounded by false cleavage planes. In most quarries, however, areas of false cleavage, when present, are readily recognizable and definitely localized, and may simply be left standing as waste.

Judging from observations by the writer as well as the statements of quarrymen, the eastern part of the district, especially that east of Susquehanna River, seems to have suffered more from the presence of false cleavage than the region farther west, perhaps because compression in the east was generally closer and more intense.

Jointing. It has already been pointed out that the prevailing joints are of two systems, one striking northwest and the other northeast. The former is of special economic importance in facilitating quarry

operations. The nearly horizontal joint planes already described are to be regarded as disadvantageous, rather than otherwise, since they are too infrequent to serve as quarry floors, yet are accompanied by so much shattering of the rock as to produce large amounts of waste and to permit oxidation and "rusting." Curved joints and joints intersecting at acute angles also yield waste. Several of the latter have seriously hampered quarry operations in the Peach Bottom and Peerless quarries just south of the Maryland line.

Bowles¹ mentions as prevalent in the Peach Bottom district steeply inclined, open joints, which permit unsupported masses of rock to slide into quarry pits, and states that these structures have resulted in several disastrous slides.

Locally, as at the Gorsuch open cut on the east bank of the Susquehanna, the slate is rendered impure by what appear to be joints cutting across the cleavage but "healed" with secondarily deposited quartz. Despite the reunion of opposite sides of the joint by the quartz, the slate is brittle at the joints. This is a local feature only, however.

DETAILED QUARRY DESCRIPTIONS

Thirty quarries or prospects are here described from the region west of Susquehanna River and twelve east of the river. The history of operations is given only in the more important cases. Quarries are in general numbered from west to east. Numbers correspond to those on the detailed map (Figures 84, 85) and on Plate 64 from which also the location of each quarry may be ascertained.

1, 2. *Proctor Quarries.* Two small quarries, long abandoned and south of the Pennsylvania line, show a little slate.

3, 4, and 5. Old, small openings on the state line. The slate exposed is good. Cleavage strikes N.45°E., dips 80°S.

6. *Miles Quarry.* This small opening just north of the state line, long abandoned, shows cleavage striking N.47°E. and dipping vertically. Finished slates on the dump show a somewhat rougher fracture than usual.

7. This is scarcely more than a prospect. Cleavage strikes N.50°E., dips vertically. A few prominent northeast joints are seen.

8. *Large Miles Quarry.* An irregularly shaped opening on the hill east of Delta, measuring about 250 feet square and showing 50 feet of slate above the water. The cleavage strikes N.55°E., dips vertically. At the south end several "slawnts" strike N.60°E., dip 80°N.; if these are bedding planes, the opening is thus on the north limb of an anticline. Conspicuous joints striking N.5°E. and dipping 80°N. are seen. In the middle of the northeast wall the rock is heavily shattered, due perhaps to post-cleavage movements. Slate seen on the dump is good.

An old "factory," partly dismantled, still stands. The last operations were in 1921.

9. A small prospect, 60 feet square. The cleavage strikes N.45°E., dips vertically.

¹ Bowles, Oliver, The technology of slate: U. S. Bur. Mines Bull. 218, pp. 38-39, 1922.

10. *Electric Quarry.* This opening at West Bangor, now abandoned, measures about 225 feet square. Good slate shows 5 feet beneath the surface, below which is a thickness of 85 feet of slate to water-level. The cleavage strikes N.40°E., dips 85°S. Along the northeast edge prominent joints strike N.40-60°W., dip vertically. Several "slaunts", locally quartz-covered and in places well mullioned, strike and dip approximately parallel with the cleavage.

11. Small prospect.

12. *Edward Evans Quarry.* This opening at West Bangor is about 180 feet square and shows 25 feet of slate above water level, with 10 feet of overburden above this. Cleavage strikes N.50°E. and stands vertical. Some of the slate blocks on the dump show much quartz veining; others have "knotty" cleavage surfaces, bearing small tubercle-like projections; still others show conspicuously curved cleavage with associated false cleavage. The slate produced is said to have been exceptionally hard and brittle.

This quarry was opened about 1870. It was shut down for a later period, but operations were resumed in 1905. Quarrying stopped again just before the opening of the World War.

13, 14. Two small prospects, 300 feet apart.

15. *John D. Williams Quarry.* This opening at West Bangor is 100 feet square and shows 80 feet of slate to water level. Cleavage strikes N.40°E. and dips 75°S. The quarry was opened about 1870 and shut down finally in 1885. It was planned at one time to tap the opening with a tunnel 1000 feet long driven south from the valley.

16. *John Humphrey Quarry.* This famous opening, probably the largest and one of the oldest of the district, is at West Bangor. It is 960 feet long by 120 feet wide and is said to have a total depth of about 200 feet. The cleavage strikes N.40-47°E. and dips steeply south. Numerous joints, with strikes varying from N.5°W. to N.60°W. and dipping approximately vertically, show on the walls. In addition, three well-marked shattered zones striking roughly due east, dip 15° or so to the north. They are respectively 25, 40, and 75 feet below the surface of the ground and are examples of the "big flat" joints of quarrymen; strictly speaking, they are zones of sub-parallel joints, rather than distinct joint planes; most of the steeply dipping joints stop against these.

This quarry was first opened in 1860 or even earlier. Operations were resumed after temporary discontinuance several times, the last work being done in 1911. It, too, was to have been reached by the tunnel mentioned in connection with Quarry No. 15. A large factory for producing grave covers was part of the enterprise.

17. *McLaughlin Quarry.* A rectangular opening east of the north end of the Humphrey quarry; measuring 215 by 125 feet, and showing 65 feet of slate above water level. The cleavage strike is N.55°E., the dip 80°N. at the surface, but steepening downward to vertical and then turning to 85°S. at the bottom. In the northeast and southwest walls numerous parting planes or "slaunts," 2 to 10 feet apart and some of

them loose, like "loose ribbons," strike $N.55^{\circ}E.$, dip $75^{\circ}S.$ If these are correctly interpreted as bedding, the quarry is opened on the south limb of an anticline, a feature which continues into adjacent quarries to the east. In the northeast and southwest walls there is a marked shattered zone already described (see page 368). Near the southeast wall, between the wall and the slip-zone mentioned, cleavage planes are locally quartz-bearing.

The quarry was operated in the early nineties for a few years only. It was intended to work the same beds as in the R. L. Jones quarry but the opening should have been carried farther northwest.

18. *R. L. Jones Quarry.* This quarry, the oldest on the slate ridge, is also one of the largest. It is an irregular opening 800 feet long and about 100 feet wide. "Slaunts" strike $N.50^{\circ}E.$, dip $81^{\circ}S.$, whereas the cleavage averages $N.53^{\circ}E.$ in strike and $87^{\circ}S.$ in dip. Among numerous joints studied, a $N.25-70^{\circ}W.$ system, with dips of 45° to $80^{\circ}S.$, predominates.

This quarry was opened approximately in 1850, and run at intervals until 1912. It is northeast of West Bangor.

19. *Johnson Quarry.* This opening $1\frac{1}{2}$ miles northeast of Delta was once three separate quarries, now united into one. The slaty cleavage is largely folded, in places very heavily so, and bears quartz stringers parallel to the curved cleavage planes. Many of the less irregular quartz veins have a strike identical with those in Quarries 17 and 18 to the west, and apparently belong to the same set. The cleavage strike is $N.50^{\circ}E.$, with vertical dips.

This large opening is operated by the Funkhauser Company of Hagerstown, Maryland. The plan is to work several benches, using churn drills and powder. Drilling is carried to depths of 100 feet before blasting; power shovels are used for loading. A gasoline engine hauls the loaded cars to the mill, where the slate is crushed for roofing granules.

20. *Kell Quarry.* A small opening, now largely filled with rubble. The cleavage strikes $N.50^{\circ}E.$ and dips $85^{\circ}N.$

21. A small pit, virtually a prospect. The cleavage is excellent; it strikes $N.40^{\circ}E.$, dips $88^{\circ}S.$

22. *Hughes Estate Quarry.* This small opening shows good cleavage that strikes $N.33^{\circ}E.$ and dips $76^{\circ}S.$ The slate contains thin quartzitic lenses, evidently representing sandy laminae, which dip more gently than the cleavage and thus suggest the south limb of an anticline.

23. *Lloyd Quarry.* A small, long-abandoned opening, only 20 feet deep. Cleavage strikes $N.55^{\circ}E.$ and dips $85^{\circ}S.$ The slate on the dump splits evenly and well. The quarry was once operated to produce graphite filler.

24. *Stewart Quarries.* Two small openings 100 feet apart, both long abandoned. The slate shows good cleavage, which strikes $N.50^{\circ}E.$ and dips $70-75^{\circ}S.$

25. Small prospect only.

26. *Faulk Jones Quarry.* This large opening two miles northeast of Delta at Slate Hill is now abandoned. It shows 60 feet of slate above the water, but is probably about 100 feet deep. The cleavage strike averages $N.45^{\circ}E.$, dips vertically. Jointing is conspicuous, the dominant system striking about $N.35^{\circ}W.$ and dipping vertically. One joint—or more properly a zone of irregularly uniting and separating joints of the “big flat” type—shows about 30 feet below the surface along the northwest wall. Especially conspicuous also is a set of curved parting planes suggestive of an anticlinal crest and so interpreted here; this is best developed on the northeast quarry wall.

The slate on the dump shows excellent cleavage, but some cleavage surfaces bear the tubercle-like projections mentioned elsewhere; larger siliceous knots are also seen locally, and some of the slate has developed the small spots of rusting mentioned on page 379.

This quarry was operated in part by tunnelling into its southwest wall. It was opened about 1860. The latest work was done in 1922, and the buildings are still standing.

27. An old, long abandoned opening. It shows a vertical thickness of 12 feet of slate, with cleavage striking $N.47^{\circ}E.$, dipping $85^{\circ}S.$ The slate on the dump generally has rough cleavage planes.

28. *Slate Point Quarry.* This consists of a small tunnel and an open cut above it in the bluff overlooking the river. The beds strike $N.40^{\circ}E.$ and dip $80^{\circ}S.$; cleavage dips slightly less than the beds, and the structure thus probably represents the south limb of a northward-tilted syncline. Jointing is of two sets, one dipping $30^{\circ}S.$, with strikes of $N.60^{\circ}W.$, the other being virtually horizontal (“big flat” joint type). There is considerable quartz and calcite veining parallel to the cleavage, which locally shows folding and is crossed by false cleavage.

This quarry was last worked about 40 years ago. A small hole to the east was the site of later small-scale operations.

29. *Bonsell and Yard Quarry.* A small quarry in the east bluff of the river showing good cleavage which strikes $N.33^{\circ}E.$ and dips $80^{\circ}N.$ This was once a much larger opening; the waste was thrown into the river and filled the raft course, so that an injunction to prevent quarrying was granted by the court.

30. *Gorsuch Open Cut.* This quarry in the east bank of the Susquehanna is very irregular in outline, but roughly 200 feet square. The hillside rises to the east, hence depth beneath the surface was attained in that direction and better slate produced. Cleavage generally strikes $N.40-50^{\circ}E.$ and dips variously, from $80^{\circ}N.$ to $70^{\circ}S.$ “Slaunts” (bedding planes?) strike $N.43^{\circ}E.$ and dip $85^{\circ}N.$, which, with the cleavage dip mentioned, suggests the south limb of syncline. The dominant joints strike $N.30-60^{\circ}W.$ and dip $30-70^{\circ}S.$ They, as well as some of the cleavage planes, are coated with quartz and calcite and both types of coating show mullions. A heavily broken zone parallel to the cleavage and several curved parting planes suggestive of bedding shatter the slate near the middle of the northeast wall. A similar shattered zone appears still farther south on this wall. From these

facts it is obvious that most of the material quarried could not be used for making roofing slate.

This quarry was first worked in 1852. In the beginning much roofing slate was made, 20-inch sizes being the operators' specialty. Quarrying was, however, discontinued in 1877 for the same reason as at Quarry No. 29. In 1918 a mill was built to crush the product into granules for roofing. Later, however, operations were discontinued.

31. *Smaller Gorsuch Quarries.* These two openings are about 200 feet apart. The more southerly one shows 40 feet of slate above the water level. Its cleavage strikes N.35°E., dips 75°S. "Slaunts" strike N.25°E. and dip 80°S.; hence the structure is as in the Gorsuch Open Cut, described above. Along some of the "slaunts" the cleavage shows pronounced drag, as though there had been movement later than the growth of the cleavage; in such zones of "dragged" cleavage, false cleavage is seen.

The north quarry is 60 feet deep. The cleavage strikes N.28°E., dips 80°S. A prominent series of quartz fillings is seen in the cleavage planes, evidently the eastward continuation of those in the Gorsuch Open Cut. Dominant joints strike N.60-70°W. and dip steeply south.

32. *McSparran Quarries.* These two small openings, about 150 feet apart, have long been abandoned. They show good cleavage which strikes N.50°E. and dips 75°S. They are on top of the river bluff above the Gorsuch Open Cut.

33. *Small McSparran Quarry.* A small, long abandoned opening.

34. *Shank Quarry.* This quarry on top of the bluff at Whitaker station measures 100 by 50 feet, and exposes about 50 feet of good slate to water level. The cleavage strikes N.35°E. and dips 75°S. The south dip of the cleavage caused an appreciable and dangerous overhang. Further, there was considerable shearing with some decay along many of the joints. Opened in 1895, the quarry could not long be operated in face of these difficulties.

35. *Cooney Quarry.* This is a circular hole, 50 feet in diameter, half a mile south of Greene. Slate on the dump has good cleavage. Operations must have ceased long ago, probably as early as 1870.

36. *Finley Quarry.* This opening, half a mile southeast of Greene, is about 130 by 50 feet in plan and 25 feet deep. The cleavage strikes N.38°E. and dips 65°S. The slate on the dump is of fair grade, but much of it shows false cleavage.

37. *Gregg Quarry.* This is a small hillside cut, operated chiefly to supply local farm-houses with roofing. It is on Peters Creek east of Greene. The cleavage strikes N.43°E. and dips 78°S. Grain trends N.45°W. and dips 60°E. "Slaunts" strike N.42°E., dip 85°S.; hence this is on the south limb of a syncline. The "slaunts" are so closely spaced as to interfere with the production of large roofing slates. The quarry was last operated in 1870.

38. *Old Graybill or Tanyard Quarry.* A small hole, 50 feet square



A. Single-mast supports for cables, commonly used in quarrying in the Peach Bottom district.



B. View of Gorsuch open cut; note numerous joint planes dipping gently to left.

and 25 feet deep, on Peters Creek above the Gregg quarry. The cleavage strikes N.38°E. and dips 65°S. Much of the slate is affected by false cleavage.

HISTORY OF SLATE QUARRYING IN THE PEACH BOTTOM DISTRICT

Excellent brief descriptions of the development of slate quarrying in this district have been given by Mathews¹ and Ferguson²; the writer is also indebted for much information to various residents in the region.

It is generally believed that the oldest slate now available is that on the trip hammer shop of Will Coleman's place at Peach Bottom, east of Susquehanna River; this was first placed by Joseph Hewes, of North Carolina, a signer of the Declaration of Independence. It has since been relaid four times and pieces of it, drilled for rectangular hand-wrought nails, are still in use. In approximately 1785 William Decker is reported to have carried on the first actual quarrying on a marketable basis and local slate was used in roofing the old Slate Hill Church east of West Bangor, which was built in 1805. Following Mathews, this may be regarded as the early stage in the development of the slate industry.

At a much later date, variously given as 1845 and 1846, Welsh immigrants entered the district. Among them were professional slate quarrymen and quarrying on a larger scale began in earnest. In 1850 samples of Peach Bottom slate were awarded a prize at the Crystal Palace exposition near London. The first large-scale quarrying was at the site of the present Jones quarry³. At first the operators found competition from Welsh slate, which was brought into the United States duty-free, ruinous, but by 1850 the quarry industry on both sides of the river was in full swing. In 1858 Rogers reports in the entire district 18 quarries west of the river and 11 east of it⁴, and mentions specifically the Perry (or Parry) quarry east of the Susquehanna and the Brown and Slate Hill (or Slate Point) quarries west of the river; Frazer in 1880 gives an apparently incomplete record of 17 quarries in Pennsylvania and Maryland⁵.

Previous to 1850 quarrying was not carried to great depths and usually stopped where weathering became slight and solid slate had to be handled, because blasting was not used and the difficulties of operation increased the cost too greatly. By 1880, however, operations were essentially as they are today, and quarries were readily carried to depths of 100 feet or more. Channellers and broaching, however, were still not in use, and the chief production was roofing slate, though mantels and tombstones are mentioned and one mill for pulverizing slate was active in 1880⁶, the product being used in cement and paint and for roofing granules.

¹ Merrill, G. P. and Mathews, E. B., *The building and decorative stones of Maryland*: Md. Geol. Survey, vol. II, pp. 215-221, 1898.

² Ferguson, E. G. W., *Peach Bottom slate deposits, Pennsylvania*: Mining World (Chicago), vol. 33, pp. 183-184, 1910.

³ Merrill, G. P., and Mathews, E. B., *op. cit.*, p. 216.

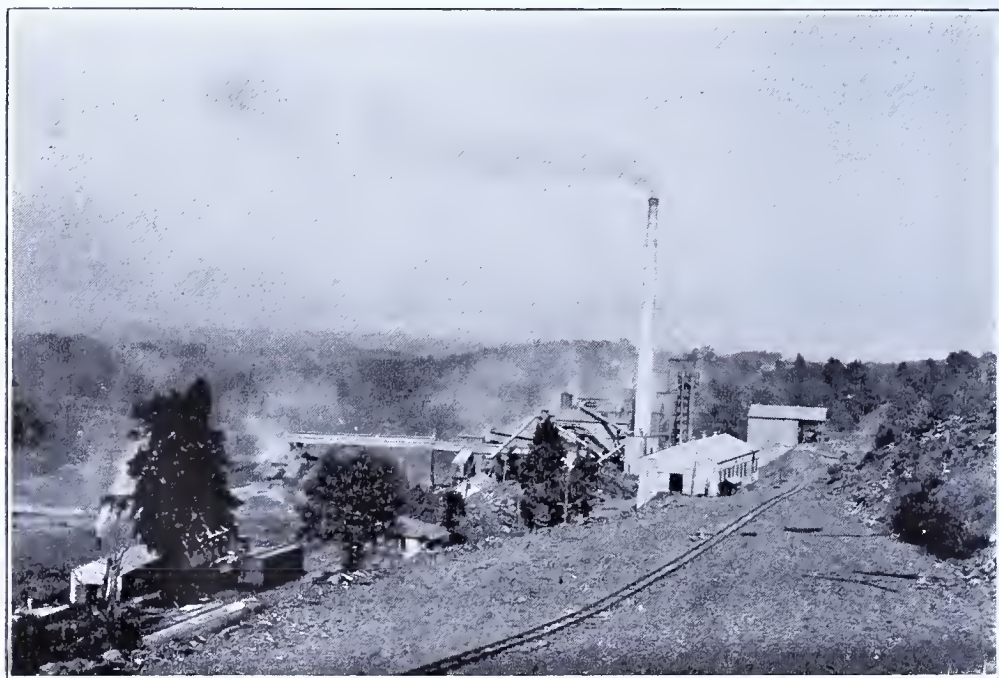
⁴ Rogers, H. D., *The geology of Pennsylvania*, vol. 1, pp. 188 and 189, 1858.

⁵ Frazer, Persifor, Jr., *Geology of Lancaster County*: Pa. Second Geol. Survey Rept. CCC, pp. 179-180 and 183-190, 1880.

⁶ Frazer, Persifor, Jr., *op. cit.*, p. 182, 1880.



A. Typical mill and roofing slate stock pile, Peach Bottom district.



B. Mill for crushing slate, Blue Mountain Stone Company, near Delta, Pa.



A. Slate tombstones at Mt. Nebo Cemetery, Slate Hill; dates are 1852 and 1872.



B. Foundation of a store in Delta, built in 1895, of Peach Bottom slate.

In the present century individual quarries suffered interruption of operations, largely because of competition from other American districts, but with the beginning of the World War slate production once more increased, and some 20 openings were operated at intervals in Pennsylvania alone. This expansion took place, thanks in part to the use of electricity in place of steam, but because of other technical improvements as well. It has only been since the end of the war that a general slump in the industry set in. The limited uses for which Peach Bottom slate could be machined and the severe competition from the better organized Lehigh-Northampton firms and those in slate regions outside the State, combined to strain the Peach Bottom producers beyond capacity. The only production of commercial slate in this district now comes from two companies jointly operating a single opening in Harford County, Maryland, and from three others that quarry and crush slate. Of the latter only one is in the State of Pennsylvania. All of the other quarries are abandoned temporarily or permanently.

PRODUCERS OF SLATE IN PENNSYLVANIA IN 1931

Lehigh-Northampton District

LEHIGH COUNTY

| | |
|-------------|---|
| Slatedale: | J. P. Kern Slate Co.
Royal Blue Slate Co.
Shenton Slate Co. |
| Slatington: | American Slate Quarries
Blue Mountain Slate Manufacturing Co.
Blue Ridge Quarries (Inc.)
Cambridge Slate Co.
Manhattan Slate Co.
Pennsylvania Slate Blackboard Co.
Slatington Slate Co. |

NORTHAMPTON COUNTY

| | |
|-------------------|--|
| Bangor: | Bangor Fidelity Slate Co.
Bangor Ideal Slate Mining Co.
Bangor Quarry Co. (address, 1920 E. Seventy-fifth St.,
Cleveland, O.)
Bangorvein Slate Co.
Columbia Bangor Slate Co.
North Bangor Slate Co.
Old Bangor Slate Co.
Slate Products Co. |
| Berlinsville: | Amalgamated Slate Quarries Co. (address, Easton) |
| Chapman Quarries: | Chapman Slate Co. (address, Bethlehem) |
| Edelman: | The Hard-Vein Slate Co. (address, Easton) |
| Nazareth: | Edelman Standard Hard-Vein Slate Co. (address,
Edelman) |
| Pen Argyl: | Albion Vein Slate Co. (address, Bangor)
Belmont Slate Co. (address, Bangor)
Diamond Slate Co. (Inc.)
Doney Slate Co. (Inc.)
Jackson-Bangor Slate Co.
Keenan Structural Slate Co.
Parsons Bros. Slate Co.
Parsons Manufacturing Co.
Stephens-Jackson Co.
D. Stoddard & Son (address, Bangor) |
| Windgap: | Bolger-Heller Slate Co.
Colonial Slate Co. (address, Bangor)
Imperial Slate Blackboard Co.
Phoenix Slate Co. |

Peach Bottom District

YORK COUNTY

| | |
|--------|---|
| Delta: | Funkhouser Co. (address, Hagerstown, Md.) |
|--------|---|

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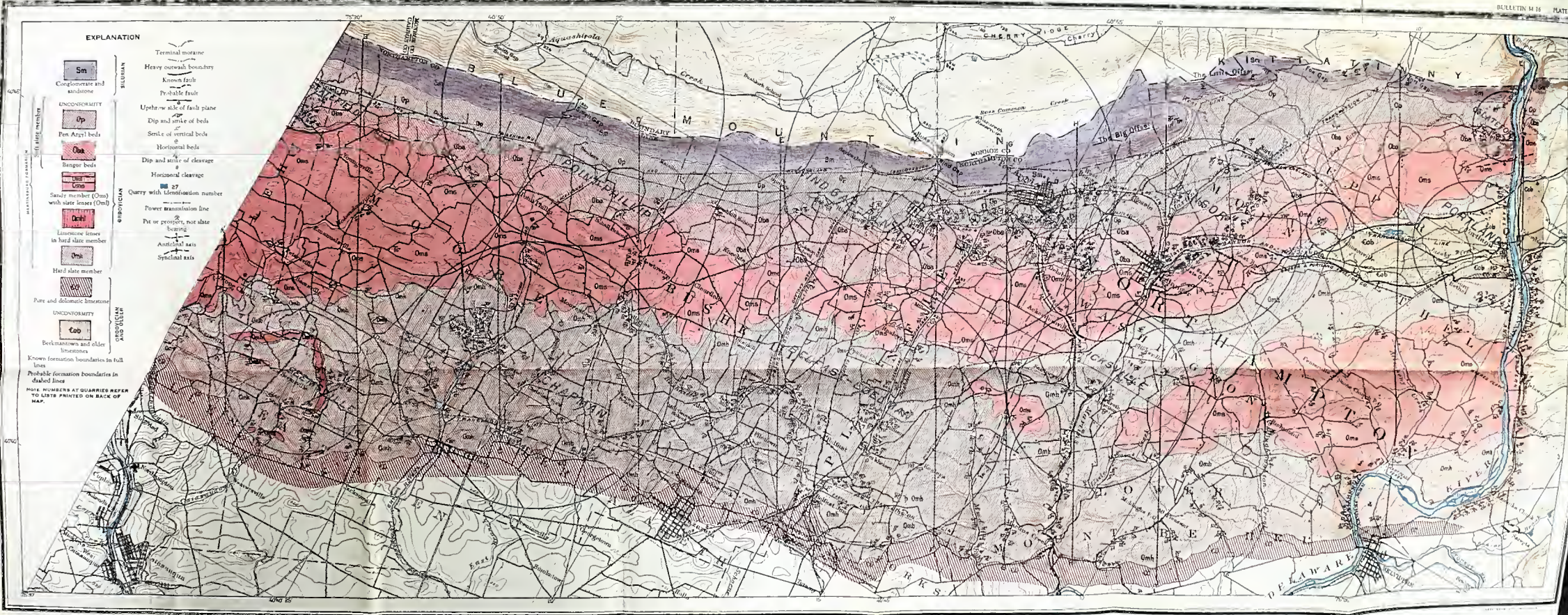
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GEOLOGIC MAP OF SLATE BELT IN NORTHAMPTON COUNTY, PENNSYLVANIA

By C. H. BEHRE, Jr.

None also

$\frac{1}{n} \sum_{i=1}^n x_i = \bar{x}$

[illegible]

Confidence interval 90% low

Base from U. S. Geological Survey
topographic maps of Delaware Water Gap,
Wood Gap, and Allentown quadrangles

SOFT SLATE QUARRIES

ALBION-BANGOR GROUP

1. Nungesser
2. Albion Bangor
3. Arvon
4. Excelite
5. Felcan
6. Tinsman
7. Allen
8. Kinney
9. Phoenix
10. Heller
11. Imperial
12. Acme
13. Alpha
- 14.
15. Albion Superior
16. Stoddard
17. Dick
18. Martin and Harding
19. Doney's Old
20. Grand Central
21. Small Grand Central
- 22.
23. Doney
24. New Diamond
25. Parsons
26. Albion Veto
- 27.
- 28.

PINE PHILLIP GROUP

- 1.
2. } West End
3. } St. Nicholas
4. Beers
5. Young

WIND OAT PEN ARCYL GROUP

33. Pennsylvania
34. Diamond
35. Jackson Bangor No. 6
36. Jackson Bangor No. 6 (Small)
37. Jackson Bangor No. 5 Valley
- 38.
- 39.
40. Old Crown
41. Crown
42. Bangor Fidelity
43. West Bangor
44. Bangor Superior (Small Quarry)
45. Bangor Superior
46. Kellers
47. Stocker
48. } Ulster
49. } American Bangor
50. } Bangor Southern
51. } Reichard
52. } Delahole
53. } Delahole
54. } Delahole
55. } Delahole
56. } Delahole
57. Nagel

SLATESFORD GROUP

- 1.
2. Washington Brown
3. Williams
4. Swedson
5. Frye

BANGOR GROUP

1. New York
2. Hubokem
3. Strunk
4. New Peerless
5. Little Bangor
- 6.
7. Mountain View
8. Consolidated No. 1
9. Shiner
10. Consolidated No. 2
11. Consolidated No. 1, No. 2
12. Standard
13. Bangor Valley (Former Eclipse)
14. Bangor Central
15. Bangor Royal
16. Columbia Bangor New Bangor
17. Bangor Escelton
18. Old Bangor
19. North Bangor No. 1
20. North Bangor No. 1
21. Bangor Union
22. Bangor Washington
23. Northampton
24. Shaft on Blake's Property

SLATESFIELD GROUP

1. Sep
2. Lebas
- 3.
- 4.
5. Langenbach
6. Langenbach
7. Langenbach
8. Williams
9. Williams
10. Williams

HARD SLATE QUARRIES

CHAPEMAN GROUP

1. Graber
2. The Weidman's
3. Ryan
4. Delehenn
5. Chapman Stanlad
6. Chapman (two holes)
7. Keystone
- 8.
9. Wagner
10. Fisher No. 2
11. Fisher No. 1
12. Lilly No. 1
13. Lilly No. 2
14. Fisher No. 3
- 15.
16. Mauch Chunk
17. Chapman Superint
18. Ed Smith
19. Haggenbach
20. Turner
21. Resling
22. Magee
23. Rippon and Wells
24. Schegel
25. Steel No. 1
26. Steel No. 2
27. Dick
- 28.
29. Rhynes
- 30.
31. Rush
32. Achenbach
33. Fleichman
34. Daniels
35. Bader
36. Roon
37. Meyer
- 38.

DEPAST BOREMAN GROUP

1. Bata
2. Gera
3. Lohr
4. Edelem
5. Barnett
6. Pennsylvania
7. Seem
8. Allen
9. Northampton
- 10.
- 11.
12. Theodor Whitell
- 13.
- 14.
15. Ditchard
16. Old Bell
17. Bell
- 18.
19. Henry
- 20.

DEPAST BOREMAN GROUP

1. Pryor
2. Doss
3. Wagner
4. Tapp
5. Fitch
6. Delahole

DEPAST BOREMAN GROUP

1. Koch
- 2.
3. Ziegenfuss
- 4.
- 5.
6. Miller
7. Miller No. 2

PORTLAND GROUP

1. Northampton
2. Mt. Bellel
3. Phillips
4. Miller

NOT GROUPED

Half mile due west of Johnstown



SOFT SLATE QUARRIES

SLATINGTON GROUP

1. Old Diamond
2. New Diamond
- 3.
- 4.
5. Fresh Bottom
6. West Highland
7. Highland
8. Blum-not
9. Sargeville and Hope
10. Fensermacher and Roth
11. East Sargeville
- 12.
13. Philadelphia
14. Bitner
- 15.
16. Mack
- 17.
- 18.
19. Columbia
- 20.
21. Bloos
22. Locke and Royal Blue
23. Manhattan and Schuylkill
24. Kern
- 25.
26. Standard
27. Rice
28. Myers
29. Blue Mountain
30. Bucktown (Dillard)
- 31.
32. Roberts and Peters
33. Kram
34. Empire
35. Coates
- 36.
37. Ellis Owens
38. Owens Williams
39. Parry
40. Emerald
- 41.
42. Old Franklin
43. Big Franklin

PROVIDENT AND HAZEL DELL

- Peters
- Fairview, East Carbon, Old Columbia
- Williamstown
- Hughes
- Roth
- Blue Valley
- Eutels and Mountain
- Pittston
- East Berlin
- Penn Leno
- Blue Ridge
- Old Crimbridge and Pennsylvania-Star
- Cambridge Shale
- Blue Diamond
- Thomas and Roberts
- Stolz
- Welshtown Tunnel and East End
- Fullmer and Keystone
- New York Tunnel
- Rice
- Lehigh Gap and Bill Hughes
- Locust
- Riveride
- Caskey and Emark
- West Brensinger
- David Williams
- Peters
- Rudolf
- Heimbach
- Franklin
- Big Franklin

BENNINGER

89. Oak Hill and Loretto
- 90.
91. Old Griffith
92. Peters
93. Hughes and Griffith
94. Peters-Arlas
95. Provident
96. Genuine Washington
97. Atlas
98. Roberts
99. Hahn and Griffith
100. John Benninger
- 101.
102. Seybold
103. Prudential
- 104.
105. Binnet
106. Oplinger
107. Madoc
108. Pearl (York-Lien)
109. West Montgomery
- 110.
111. East Montgomery
112. Haynes
113. East Haynes
114. Williams
115. Aensiento
116. Continental
117. Wales-Banger (Federal Slate Company)
- 118.
119. Sewell
- 120.
- 121.
122. Patsy
123. Hower
124. Gem
125. Cambria
126. National
127. Rept
- 128.
- 129.

LYNNPORT GROUP

1. Hemetley
2. Mammoth
3. Oswald
4. Quaker City
- 5.
6. Centennial
- 7.
8. Pittsburgh
9. Daniels
- 10.
- 11.
12. Kalbach
13. Roberts
14. North Kutler
15. South Kittler
16. Henry
17. South Germany
18. North Germany
- 19.
20. South Shenton
21. Shenton
22. Hess (Ontelaunce)
23. Kuntz
24. Bauer
25. Laurel Hill
26. Mosserville
27. Sieger and Kraus
- 28.

HARD SLATE QUARRIES

COLORED CLAY SLATE QUARRIES

LOWELL GROUP

1. Flint Hill
2. Bachman
3. West Clausville
4. East Clausville

GREENWALD GROUP

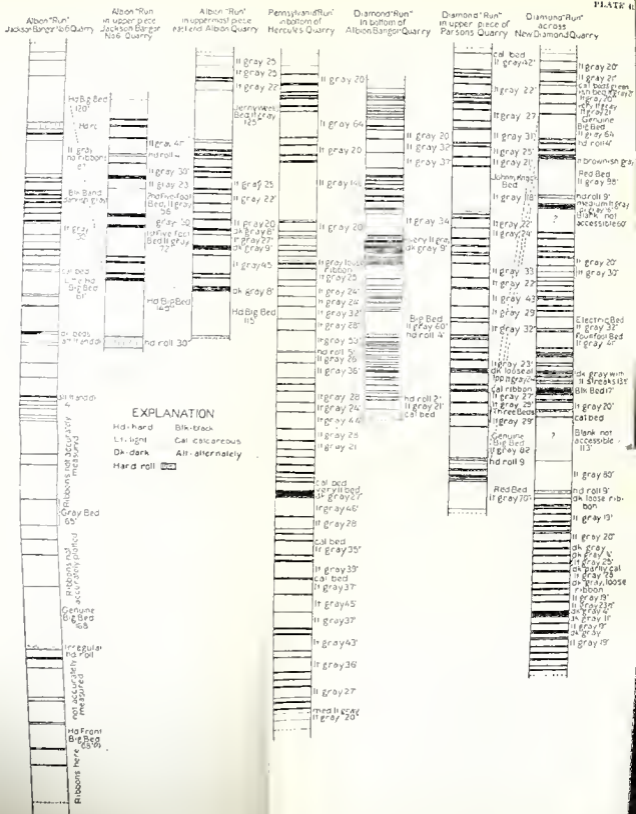
1. Albany
2. Roth
3. Wilbur
4. Focht
5. Lenhartville

TRICHLIFAS GROUP

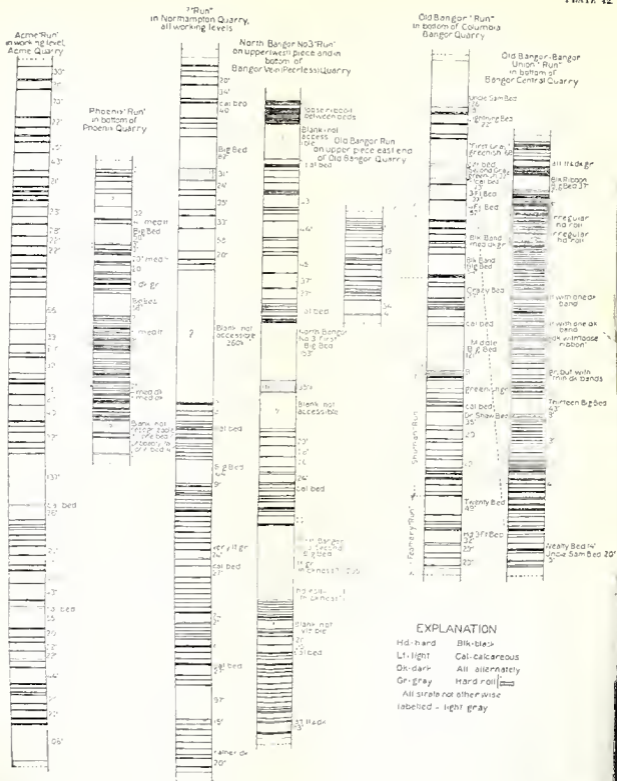
- 1.
2. Rockdale
3. Big Rock
4. Frantz
5. Roth
6. North Cementon
7. South Cementon
8. Reservoir
- 9.
- 10.
- 11.

WALBERTS GROUP

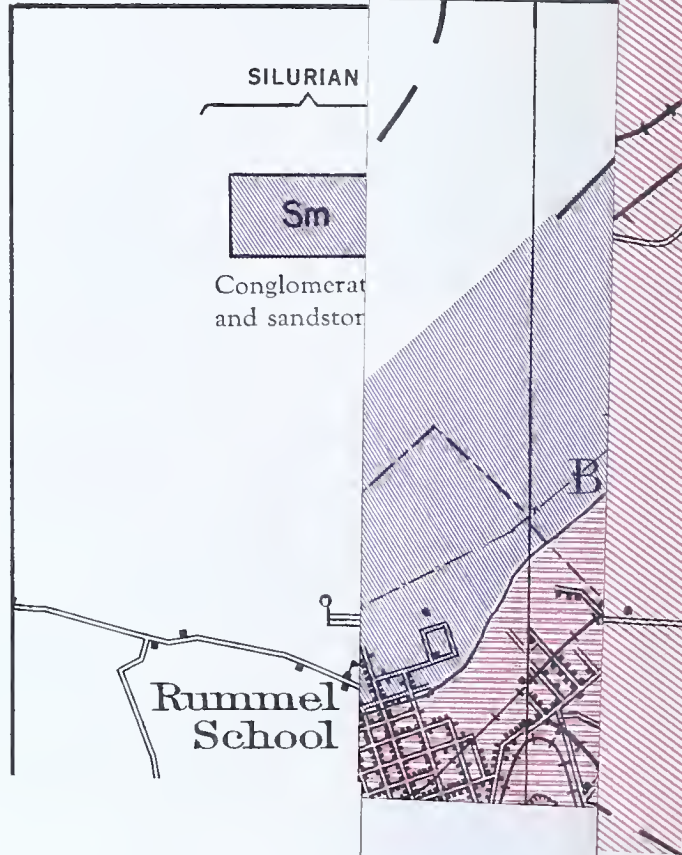
1. Snyderville

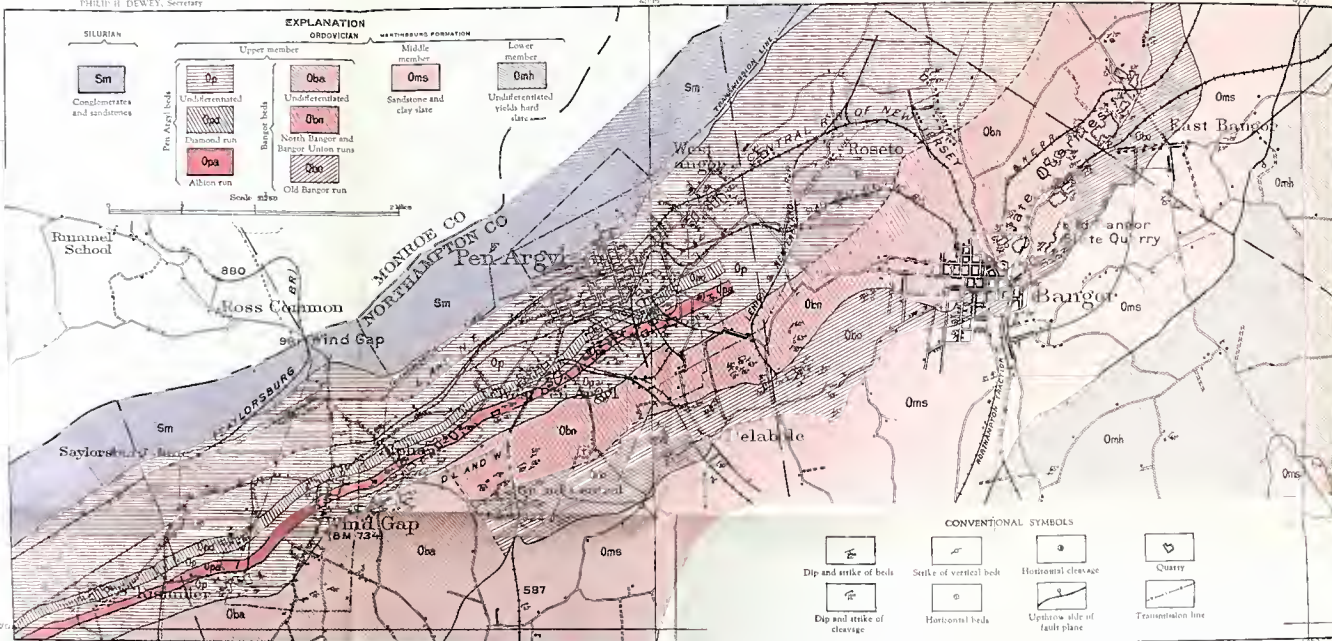


Thickness measurements in 1701 Argyl beds. Scale 1 inch=200 inches.



COMMONWEALTH
DEPARTMENT OF GEOGRAPHIC AND 43
PHILIP H. GEORGE H. ASHL
40°15'





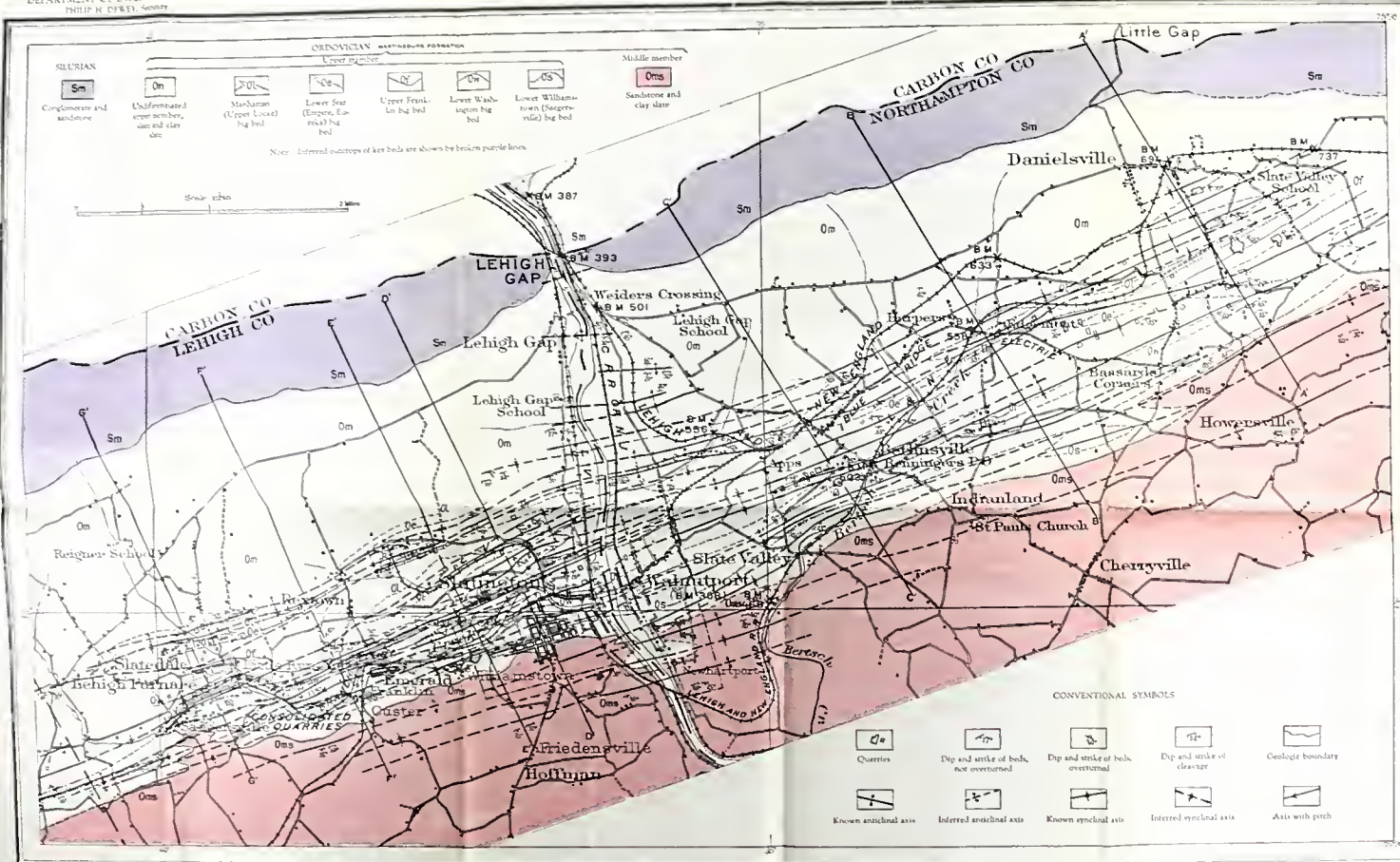
GEOLOGIC MAP OF SLATE BELT AT BANGOR, PEN ARGYL, AND WIND GAP,
NORTHAMPTON COUNTY, PENNSYLVANIA

By C. H. BEHRE, Jr.

Base from U. S. Geological Survey
topographic maps of Delaware Water Gap
and Wind Gap quadrangles.
Contours, etc., added by
J. A. and C. H. Behre, Jr.

40' 5'

SILURIAN



GEOLOGIC MAP OF SLATE BELT AT DANIELSVILLE, SLATINGTON, AND SLATEDALE.

By C. H. BEHRE, Jr.

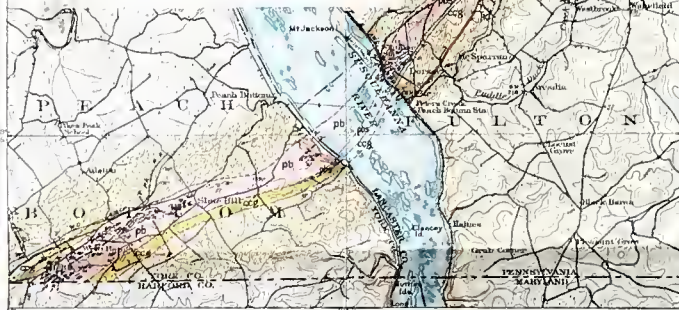
MAP OF PEACH BOTTOM DISTRICT
(Modified after Knopf and Jona)

- | | | | |
|--------------------------------|--|--------------------------------|--|
| Fault, known | | Dip and strike of cleavage | |
| Fault, inferred | | Large quartzites | |
| Formation boundary known | | (Dimensions approximate) | |
| Formation boundary inferred | | Small quartzites and prospects | |
| Dip and strike of bed | | Probable anticlinal axis | |
| Vertical beds, strike as shown | | Probable synclinal axis | |

Scale 1:25,000

Contour interval 20 feet

datum is mean sea level



Triassic



Diabase dike



Slate facies



Schist facies



Carlisle conglomerate



Peters Creek schist

Pre-Cambrian